2013

Engineering of hydroponic systems to enhance biomass of sea oats (Uniola paniculata)

Stefanie Renee Gilliam
Louisiana State University and Agricultural and Mechanical College

ENGINEERING OF HYDROPONIC SYSTEMS TO ENHANCE BIOMASS OF SEA OATS (*UNIOLA PANICULATA*)

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The Department of Biological and Agricultural Engineering

by
Stefanie Gilliam
B.S., Louisiana State University, 2011
December 2013

ACKNOWLEDGEMENTS

I would like to express my deep appreciation for Dr. Steven Hall who first sparked my interest in hydroponics and helped me continue to study the subject. I would also like to thank the other members of my committee, Dr. Richard Bengtson and Dr. Carl Motsenbocker for their participation in my academic efforts. I would also like to thank Dr. Carrie Knott and Mr. Matt Voitier for assistance with plants.

Without the Louisiana Rice Research Board funding this research would not have possible, so I would like to give special thanks to them.

Additionally, I would like to thank the Department of Biological and Agricultural Engineering, especially Ms. Angela Singleton and Ms. Donna Elisar.

Finally, I would like to thank my supportive parents, brother, and wonderful friends who have helped me through this process, especially my wonderful boyfriend, Charlie, who encouraged me countless times.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Restoration projects use native plants such as sea oats (*Uniola paniculata*) to help stabilize the coast. Sea oats are a native grass that can collect blowing sand to build dunes. Sea oats used in the restoration projects can be produced using sexual or asexual techniques. An ideal seedling would be genetically distinct, have increased seed production and germination, and have superior vegetative biomass.

Finding ways to produce, propagate, and grow coastal plants such as sea oats effectively is critical to efforts to reduce erosion. In this study, production of sea oats via greenhouse based hydroponic systems was studied. This was accomplished by using fresh, brackish, and saline water conditions and then varying the amount of phosphorus fertilizer.

Root growth was shown to be significantly affected by salinity, with an optimal salinity of 10 ppt. Phosphorus fertilizer was not statistically significant. When the mortality was investigated, there was an area of interest with a predicted mortality rate of 80%. The area was between 1.25x and 1.5x concentration of phosphoric acid and 7 and 13 ppt of salinity.

The schematics of the hydroponic system, coupled with the findings, should assist growers and researchers in optimal growing conditions under hydroponic greenhouse conditions. Further studies are needed to assess if other nutrient conditions may have significant effects, and how plants grown in a greenhouse may survive in field conditions. Ultimately, this work should contribute to efforts to effectively produce plants, which will help reduce erosion and assist in coastal restoration efforts.

CHAPTER 1. INTRODUCTION

The Louisiana coast is extremely important for providing wintering habitats to migratory birds, as well as the commercial seafood, natural gas, and petroleum industries. This region produces 30% of the nation's seafood and is the entry point for 18% of oil production and 24% of natural gas production. A fourth of the national energy depends on the coastal support facilities (Bertrand-Garcia et al., 2012; Coastal Erosion, 2012). Because this area loses more coastal wetlands than any other area in the contiguous United States, extensive restoration efforts occur each year to try to stabilize coastal areas and reduce erosion (Bertrand-Garcia et al., 2012).

Most restoration projects use native plants such as sea oats (*Uniola paniculata)* to help stabilize the coast. Sea oats are a native grass that can collect blowing sand to build dunes. Sea oats used in the restoration projects can be produced using sexual or asexual techniques. Sexual production involves collecting seeds from natural environments, while asexual production is done by dividing rhizomes of mature plants. While sexual reproduction allows for more genetic diversity, asexual reproduction allows seedlings to be produced at a faster rate. An ideal seedling would be able to be genetically distinct, have increased seed production and germination, and have superior vegetative biomass (Nabukalu, 2013). As of 2003, according to Miller et al. (2003), the use of rhizomes for restorations had not been suggested; however, Dahl et al. (1975) used divisions of established plants for dune revegetation.

The purpose of this study was to determine if there was an ideal ratio of additional phosphorus and sea salt that would increase the total vegetative biomass of sea oats. This was accomplished by using fresh, brackish, and saline water conditions and then varying the amount of additional phosphorus up to 2.5 times the recommended amount.

CHAPTER 2. LITERATURE REVIEW

2.1 Coastal Erosion

Since the mid 1970's, coastal erosion has been a growing concern for Louisiana (Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority, 1998). Within the last 50 years, the rate of land lost has reached catastrophic levels. The land loss rate is over 40 square miles per year, up from 30 square miles in the 1990's (Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority, 1998). This loss accounts for 80-90% of the wetlands lost in the continuous states. However, Louisiana only contains 40% of the nation's wetlands (Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority, 1998; Coastal Erosion, 2012). It is predicted that by 2050, Louisiana could lose more than 630,000 acres of land and, in worst-case scenario projections, Figure 2.1.1, the loss could be greater (Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority, 1998).

The reasons for coastal erosion are complex and can vary depending on the location. The erosion is caused by both natural and man-made actions (Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority, 1998). Land loss is not the only problem caused by erosion. Loss of storm buffering, increased turbidity, and decreased water quality can also be caused by erosion (Boyd and Hall, 2012).

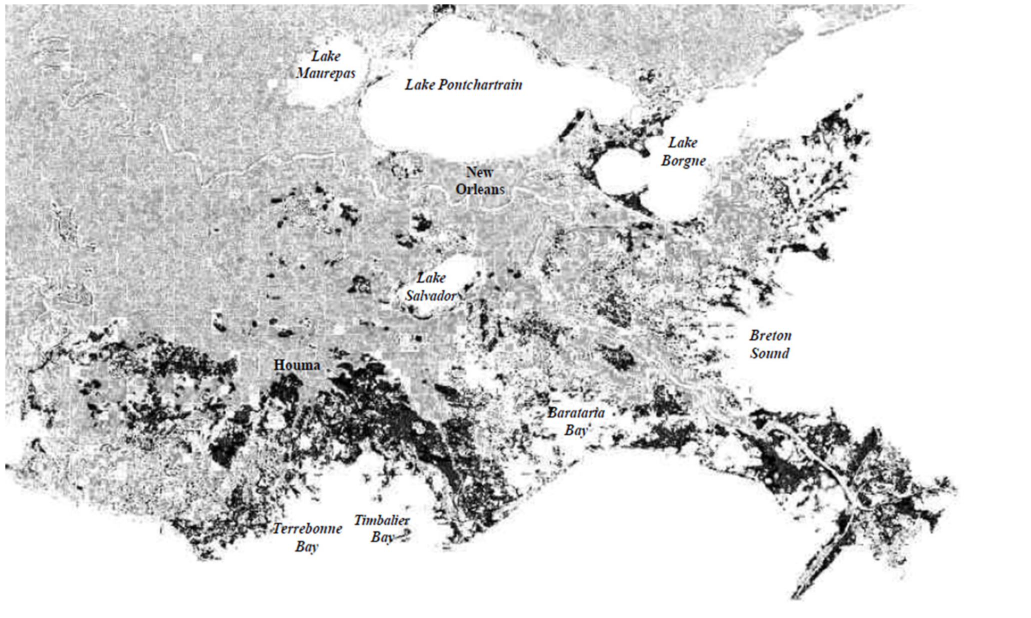


Figure 2.1.1 Expected Land Loss between 1993-2050
(Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority, 1998)

The current plan, Figure 2.1.2, to help reduce coastal erosion in Louisiana includes structural protection, bank stabilization, oyster reef creation, ridge restoration, shoreline protection, barrier island restoration, marsh creation, sediment diversion, and hydrologic restoration (Coastal Protection and Restoration Authority of Louisiana, 2012).

The preferred strategy for bank restoration has been to plant nursery-grown plants of sea oats. The transplants ideally have a rootball of 3, 5, or 10 cm in diameter. The availability and cost for transplants in large-scale renovations can be a limiting factor (Gormally and Donovan, 2010).

In the Southwest coast, Lake Charles and Abbeville area, the bank stabilization projects alone will cost 186 million dollars. This will cover over 1.2 million feet of coast with earthen fill placement and vegetative covering (Coastal Protection and Restoration Authority of Louisiana, 2012).

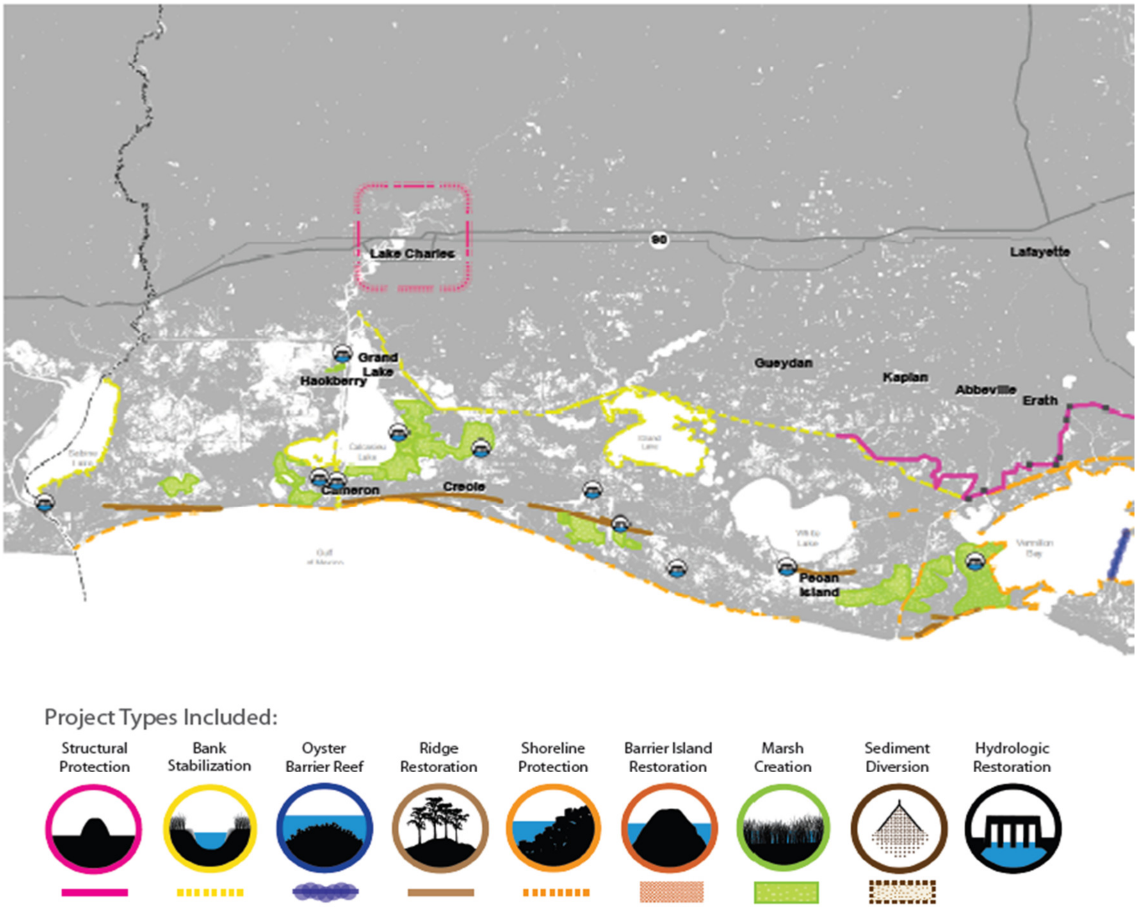


Figure 2.1.2 Coastal Restoration Projects in the 2012 Coastal Master Plan (Coastal Protection and Restoration Authority of Louisiana, 2012)

While the cost of the vegetative coverings are relative small, \$3.50/foot installed, compared to the cost of other restoration projects, \$65-450/foot installed, if the plants could be propagated in a shorter time frame, while still maintaining viable plants, the costs could be decreased further.

2.2 Sea Oats

Sea oats, *Uniola paniculata L.*, are a semi-tropical perennial dune grass that ranges from southern Virginia to eastern Mexico, Figure 2.2. At maturity, the plant can be six feet erect and has leaves, which are 24 inches long. The leaves are less than 1-inch think and brown and curled in appearance (LSU AgCenter, 2013). Sea oats have a massive root system that consists of a latticework of roots, rhizomes, and tillers. Because of this system, the plants are designed to trap blowing sand and can build up the sand dunes. As the sand is trapped by the plant, the sand burial encourages the rhizome system to spread and form either new tillers or shoots (Shadow 2007, Gormally and Donovan 2010).

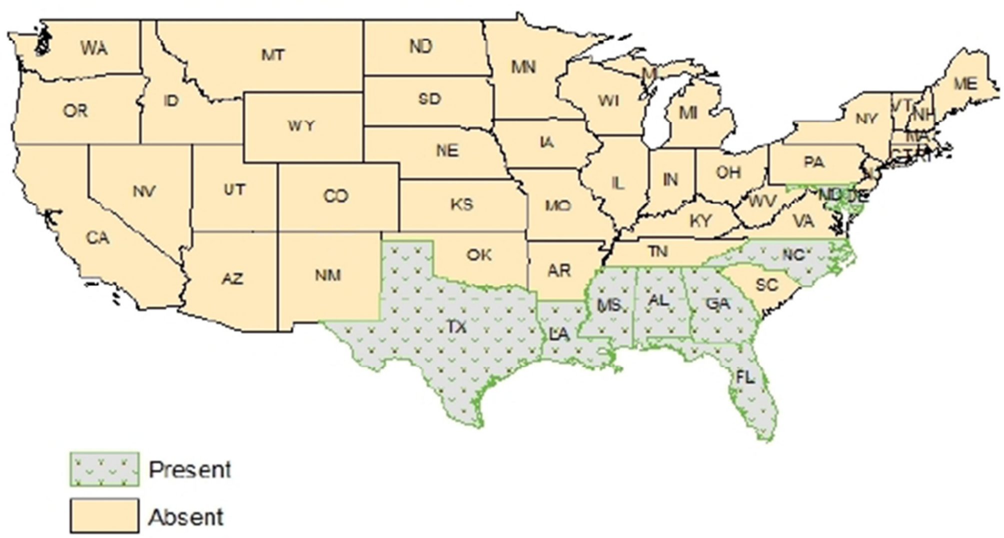


Figure 2.2. Geographical Distribution of Sea Oats (Nabukalu, 2013)

Naturally, sea oat reproduction is from rhizomes and seed production. During the summer, the leaves began to turn straw-colored and each plant will produce a seed head, or panicle (Shadow, 2007). Each panicle is made up of many spikelets, with each spikelet containing 6-8 fertile florets. However, to due environmental stresses and fungi, each spikelet will average two viable seeds. Based on past studies, the seeds have the best germination in course soil at an optimal germination temperature of 35C (95F) and a reported maximum salinity of 1-1.5% NaCl (Burgess, Blazich, Nash, 2002; Hester and Mendelssohn, 1991).

Because of the adaptations to extreme salt spray, drought-tolerant, and sand burial, sea oats can outcompete other plants in the sand dune environment (Hester and Mendelssohn, 1991). Sea oats provide both shelter and food to many animals, birds, and insects in the sand dune environment. The dune environment is not only important for wildlife, but sand dunes are important to lessen the effects of tropical storms and hurricanes on coastal communities and infrastructure (Claudino-Sales et al., 2008). The dunes not only help to stabilize the coast and provide an ecosystem, but also help in maintaining species diversity.

Because of the benefits, sea oats are often in restoration projects. The seeds are often collected for cultivation in greenhouses and propagation through rhizomes is still being researched (Gormally and Donovan, 2010). The plants are grown until they have a root ball of 3, 5, or 10 centimeters before they are used in restoration projects. This growth can take up to a year. Occasionally, the plants are grown out to larger sizes for beach environments that are exposed to repeated storm surges (Nabukalu and Knott, 2013).

2.3 Phosphorus Nutrition

Phosphorus (P) is an essential element in all living organisms and involved in many processes requiring energy (Marschner, 2012). In neutral or calcareous soils, this element is linked to Ca^{2+}, while in acidic soil it is linked to Fe^{3+} and Al^{3+}. These elements form organic or inorganic compounds that are scarcely available to the plants. This has led to plants developing root physiological strategies for P acquisition: modification of root geometry and architecture, symbiotic relationships with microorganisms, and exudation of carboxylates and phosphatases to enable solubility and/or mineralization of insoluble phosphates (Delgado et al., 2013).

Because phosphorus is essential, plants will show signs of distress if they are deficient in phosphorus such as, stunted growth, yellow or brown roots, and leaves curling and purpling. However, if the plant is exposed to high phosphorous conditions, it can develop phosphorus toxicity, which can cause the leaves to appear purple and crushed (McCauley, Jones, and Jacobsen, 2009; Aldana, 2005).

2.4 Salinity

Sea oats can tolerate being inundated with seawater for short time periods and thrive under the salt spray conditions. The salt spray is believed to provide micronutrients for the plants in the heavily leeched beach sands (Shadow, 2007). However, the sea oats can show signs of waterlogged roots within a few days. Waterlogging stress manifests in reduced biomass production and reduced leaf stomatal conductance (Hester and Mendelssohn 1987, 1989).

Some studies have been done to determine the salinity levels acceptable to sea oats, but more of the focus has been on germination as opposed to growing out rhizomes. Miller et al. (2003) did studies to determine the tiller emergence when rhizomes were exposed to a variety of saline conditions and found that the salinity did not affect the rhizomes at a low and medium levels (212-710 µS/cm) , but when the plants were exposed to high levels (1564 µS/cm), tiller emergence was affected. Seneca (1972) has found in germination studies that seeds have a low salt tolerance and that seedlings will tolerate moderate salty substrate, but growth and survival are dependent on the duration of exposure.

CHAPTER 3. MATERIALS AND METHODS

3.1 Construction of Equipment

The hydroponic system (Figure 3.1) was designed by combining two different hydroponic types: a deep-water culture and a nutrient film system. This allowed a reservoir inside the pipe, as well as recirculating water. The system was built using ten-foot long Schedule 80 poly(vinyl chloride) pipes with a three-inch inner diameter. Holes were drilled using a 2” drill bit into the pipe at eight-inch intervals allowing each pipe to support up to 15 plants. The ends of the pipe were capped with one side having a ¾-inch outlet pipe at the center of the end cap and the other side having a 15-foot long 5/8 inch flexible vinyl tube for the inflow. The outlet pipe was connected to a standpipe inside a five-gallon bucket. Each bucket had an aerator (Marina 50 Air Pump, Item B004FS592C, Amazon.com) to maintain a constant level of oxygen in the water supply. The inflow pipe was connected to an EcoPlus Submersible Pump (Item B0012V1PX2, Amazon.com) to circulate the water in the system.

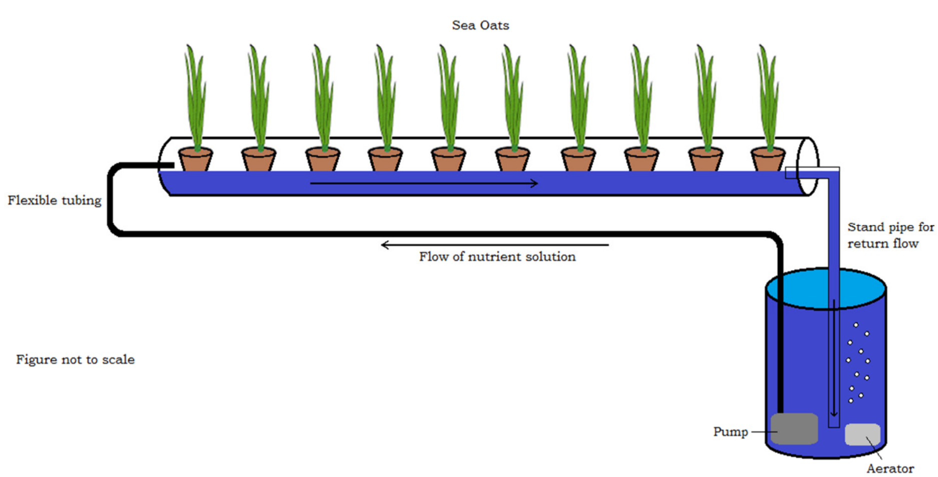


Figure 3.1. The Schematic of the Hydroponic Systems

There were twelve systems total. The systems were placed in a random order on the tables, which varied in each trial. The systems were assigned letters to aid in record keeping. The random layouts and assigned letters are shown in Table 3.1.1 and Table 3.1.2..

Table 3.1.1. Randomized System Layout

First Trial Layout	**Second Trial Layout**
C	F
B	H
K	E
G	J
E	B
A	C
F	A
H	G
J	L
L	D
I	K
D	I

Table 3.1.2 Assigned Letters to Each System

	Salinity (ppt)	**Concentration of Phosphoric Acid**
A	0	1x
B	0	1.5x
C	0	2x
D	0	2.5x
E	2	1x
F	2	1.5x
G	2	2x
H	2	2.5x
I	20	1x
J	20	1.5x
K	20	2x
L	20	2.5x

3.2 Layout of Experiment

The systems were kept in the Campus Greenhouses on LSU campus as shown in Figure 3.2.1. The greenhouse was fully enclosed with a fan and pad evaporative cooling system (Figure 3.2.2). Four systems were placed onto each table in the greenhouse (Figure 3.2.3).

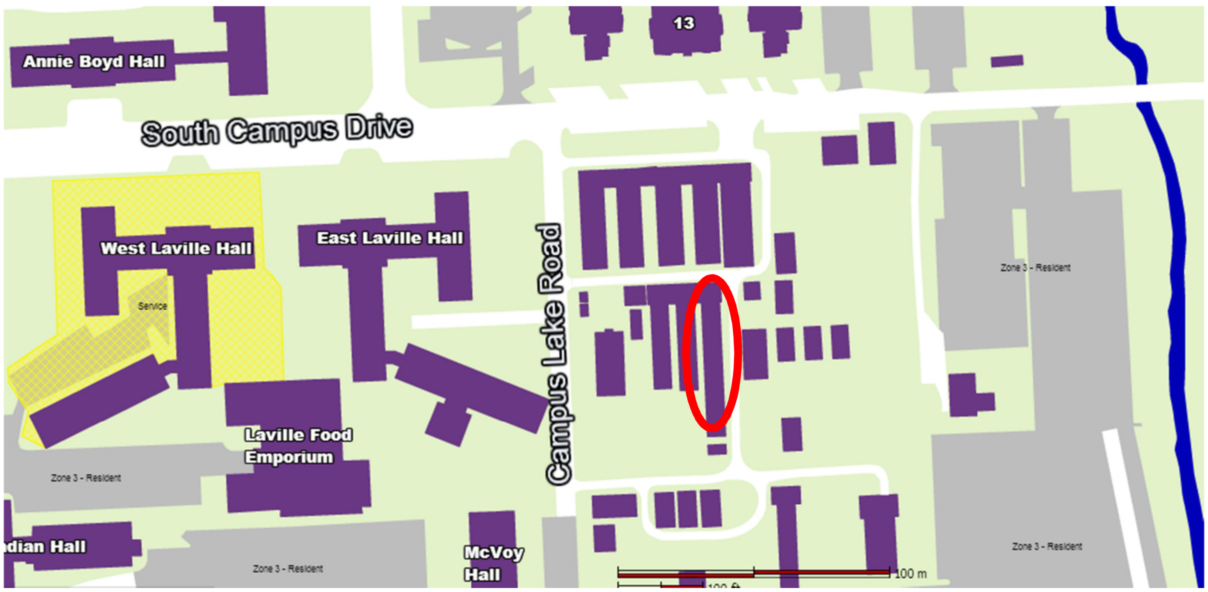


Figure 3.2.1. Location of Greenhouse on LSU Campus

Figure 3.2.2. The Greenhouse Layout

Figure 3.2.3. Four systems on a table in the greenhouse

The hydroponic solution was completely changed every 7 days. The plants were removed from the system and the buckets and pipes were drained. The buckets and pipes were fully rinsed to remove as much algae build up as possible. The buckets and pipes were refilled using tap water from the greenhouse; 11.4 mL of Hydr-Ox Hydrogen Peroxide was added to the water and allowed to circulate for 20 minutes before the other chemicals were added. After the H_2O_2 had circulated, the salt, if needed, was added, along with Ultrasol and $CaNO_3$. Then, the phosphoric acid was added to the appropriate systems. The systems circulated for an additional 10 minutes, then the plants were placed back into the system.

3.2.1 Plant Harvesting

Sea oats were first harvested from LSU Aquacultural Research Center on July 10, 2013 (Figure 3.2.4). Five plants were collected then separated into individual plants with a single root system. After the plants were rinsed in distilled water, they were placed in a bucket with two gallons of distilled water and an aerator for 48 hours. After 48 hours, the plants that had died from shock were removed. The remaining plants were randomly assigned to their location in the system and the initial weights were recorded, after air drying for two hours. The plants were then planted into net cups using rice hulls as growing medium. The plants were left in the system until 30 days had passed, then were removed, rinsed with distilled water to remove any remaining rice hulls, then allowed to dry at room temperature for 48 hrs. The final weight of the plant was then taken, along with the root and leaf weight. The sea oats for the second trial were harvested on August 30, 2013. The same procedure was used to plant and weight the plants as described above.

Figure 3.2.4. Sea Oats at the Aquaculture Research Station

3.2.2 Nutrition Solution

The nutrient solution was composed of Ultrasol Water Soluble Fertilizer 3-15-28 and calcium nitrate. This combination provided all the essential nutrients that the plants needed. By using ratios given by C.P. Hegwood, Jr. from the Burden Center, the amount of fertilizer needed was found for the smaller systems. The given amounts were 57 grams of Ultrasol and 45 grams of calcium nitrate to 30 gallons of water. This was reduced to 13.3 g of Ultrasol and 10.5 grams of calcium nitrate to supply the nutrients in a 7-gallon system. This provided 140 ppm of potassium and 82 ppm total, 67 ppm from $CaNO_3$ and 15 ppm from Ultrasol, of nitrogen.

To increase the level of phosphorus in the system, 85% phosphoric acid was added to the nutrient solution. The levels increased by 0.5x the initial concentration, up to 2.5x the initial concentration. The amount of phosphoric acid used for each concentration is shown below.

Table 3.2. mL of Phosphoric Acid Used for Varying Concentrations

Concentration	mL of Phosphoric Acid Used	Concentration in ppm
1.0x	0.0	30 ppm
1.5x	0.6	45 ppm
2.0x	1.4	90 ppm
2.5x	3.6	136 ppm

3.2.3 Additional Treatments

Instant Ocean Sea Salt Mix was added to the systems to vary the salinities and to mimic the natural sea spray. The salt mixture was added to the water before the nutrients to ensure the salt would dissolve and not precipitate out. The salinities used corresponded to the salinities sea oats would be exposed to; 2 ppt is similar to brackish water, while 20 ppt is slightly diluted sea water. Using the recommended amount from Instant Ocean, 2 ppt was made using 45.4 grams of salt mix and 20 ppt used 454 grams.

3.3 Statistical Analysis

The analysis of the weight of the plants was done using Statistical Analysis System (SAS®) programming. The plants that perished during the trial were removed from the analysis. Originally, a 2-way ANOVA test was done for preliminary statistical analysis. When no significant results were returned, the data was analyzed for polynomial regression using Proc IML with ORPOL to get orthogonal polynomial multipliers to account for the unequal spacing in the salinity concentrations. The GLMSelect program was then used to determine if there was a linear, quadratic, or cubic trend within the treatment levels. When the initial GLMSelect results showed no trend, the program was modified to retain only the data that had a significance level less than or equal to 0.05. Finally, the RSReg program was used to determine the response surface and to estimate where the optimum response values occur. The plants that perished were subsequently analyzed using the same procedure.

The complete SAS programming and results can be found in Appendix A and B.

CHAPTER 4. RESULTS AND DISCUSSION

Plant growth in the hydroponic system varied with salinity concentration and concentration of phosphoric acid. The overall plant growth was mainly in the root structure as shown in Figure 4.1. The root balls of the sea oats developed additional rhizomes along with more fibrous roots.

Figure 4.1. Root Growth on Various Plants

As shown in Table 4.1, change in overall biomass varied greatly. The first trial had an overall survivability rate of 81.25%; the second trial had a rate of 87.5%. The table also shows that in the first trial both systems F and H, 2 ppt/1.5x P_{conc} and 2 ppt/2.5x P_{conc} respectively, had a survivability rate of 50%. In the second trial, the lowest survivability per system was 75%. In addition, in trial one, system B (0 ppt/1.5x) showed that none of the plants gained biomass, but trial two did not repeat that result. The opposite was true for system C (0 ppt/2x). In trial one, three plants gained biomass, but in trial two, none of the plants gained biomass.

However, when the data was analyzed by the percentage of plants that gained biomass and survivability rate as shown in Tables 4.2 and 4.3, the highest percent that gained biomass, relative to salinity, was at 20 ppt of salinity with a rate of 87.5%, or 14 out of 16 plants. The lowest survivability rate with respect to salinity was at 0 ppt of salinity with a survivability rate of 31.25%, or 5 out of 16 plants. When the percentage of plants that gained biomass was analyzed relative to the concentration of phosphoric acid, it was found that at 1.5x the concentration of phosphoric acid, only 50% of the plants gained biomass, or 8 out of 16 plants. The highest percentage of plants that gained biomass, relative to phosphoric acid, was at 2x the concentration in Trial 1 and at 2.5x the concentration in Trial 2 at 81.25%, or 13 out of 16 plants. The highest survivability rate for phosphoric acid was found at 2x the concentration at a survivability rate of 100%. At 2.5x the concentration of phosphoric acid, the survivability rate was the lowest at 68.75%, or 11 out of 16 plants.

Table 4.1. Changes in Total Biomass of Sea Oats in Grams

Trial 1

	A	B	C	D	E	F	G	H	I	J	K	L
1	-2.8	-1.9	0.2	0.5	26.1	-3.5*	-4.2	7.2*	0.8	-1.7*	0.1	3.8
2	-0.9	-8.7	-0.5	-2.8	8.5	-2.3*	-0.1	18.1	-0.2*	9.7	4.0	1.2
3	-6.7	-8.6	1.3	-3.8	11.8	7.8	5.9	-21.5*	2.0	-1.0	1.2	0.3*
4	4.8*	-0.4	17.6	-0.2	-5.8*	8.5	0.5	2.0	-0.6	7.2	3.1	-1.3

Trial 2

	A	B	C	D	E	F	G	H	I	J	K	L
1	-6.1	2.7	-3.2	8.7	17.2	-11.6*	-11.3*	-8.9	-1.2	8.4	5.2	13.9
2	4.9	13.6	-8.4	-2.7	-0.4	4.3	-18.1	1.8	-2.9*	9.6	9.9	6.6
3	29.4	0.3	-33.1	-24.4	15.5	-2	1.7	1.9	6.4	16	12.3	26.5
4	0.5	-13.6*	-2.2	1.8*	-7.4*	2.8	4.1	12.6	7	8.1	6.5	12.3

* Plants perished before end of trial

Table 4.2. The Percentages of Sea Oats that Gained Biomass of Each Salinity and Phosphoric Acid Concentration

	0 ppt of Salinity	**2 ppt of Salinity**	**20 ppt of Salinity**
Trial 1	31.25%	62.5%	68.75%
Trial 2	62.5%	56.25%	87.5%

	1x Concentration of Phosphoric Acid	**1.5x Concentration of Phosphoric Acid**	**2x Concentration of Phosphoric Acid**	**2.5x Concentration of Phosphoric Acid**
Trial 1	62.5 %	50%	81.25%	68.75%
Trial 2	68.75%	68.75%	62.5%	81.25%

Table 4.3. The Percentages of Sea Oats that Survived of Each Salinity and Phosphoric Acid Concentration

	0 ppt of Salinity	**2 ppt of Salinity**	**20 ppt of Salinity**
Trial 1	93.75%	68.75%	81.25%
Trial 2	87.5%	81.25%	93.75%

	1x Concentration of Phosphoric Acid	**1.5x Concentration of Phosphoric Acid**	**2x Concentration of Phosphoric Acid**	**2.5x Concentration of Phosphoric Acid**
Trial 1	81.25%	81.25%	100%	68.75%
Trial 2	87.5%	87.5%	93.75%	93.75%

While the initial analysis did not show any significant trend with the salinity or phosphoric acid concentrations, further analysis using the SAS® GLMSelect program with the significance level of $\alpha = 0.05$ showed that the salinity concentration was significant, but the phosphoric acid concentration was not. Only the salinity met the significance level in both the Type I and Type III Sum of Squares as shown in Table 4.4. In the Type I Sum of Squares, salinity had an F-value of 6.59 with a Pr of 0.0123, salinity*salinity had an F-value of 5.41 with a Pr of 0.0227, and salinity*salinity*concentration* concentration*concentration had an F-value of 5.89 with a Pr of 0.0176, which makes all of these interactions significant.

In the Type III Sum of Squares, all of the interaction came back as significant with salinity and salinity*salinity having the smallest Pr value. The equations found in the Type III Sum of Squares can be used with the estimates for a Response Surface Plot, Figure 4.2 to determine the maximum interaction between salinity and phosphoric acid concentration.

From the Contour Fit Plot (Figure 4.2), the growth changes are shown with respect to the salinity and phosphoric acid concentrations. From this plot, the maximum growth was found at 1x the concentration of phosphoric acid and 10 ppt of salinity indicating that these are the optimal conditions for plant biomass growth. As shown by the superimposed box, an optimal range of salinity would be between 7-13 ppt. This result can also be found in the response surface graph, shown in Figure 4.3.

Table 4.4. The Results from the GLMSelect Program with sl = 0.05

Source	DF	Type I SS	Mean Square	F Value	Pr > F
sal	1	511.6138462	511.6138462	6.59	0.0123
sal*sal	1	420.4933343	420.4933343	5.41	0.0227
sal*conc*conc	1	53.0584170	53.0584170	0.68	0.4112
sal*conc*conc*conc	1	0.0000658	0.0000658	0.00	0.9993
sal*sal*conc*conc	1	257.1974221	257.1974221	3.31	0.0729
sal*sal*con*con*conc	1	457.7405100	457.7405100	5.89	0.0176

Source	DF	Type III SS	Mean Square	F Value	Pr > F
sal	1	975.4054217	975.4054217	12.56	0.0007
sal*sal	1	955.1301206	955.1301206	12.29	0.0008
sal*conc*conc	1	525.5948595	525.5948595	6.77	0.0112
sal*conc*conc*conc	1	454.1255805	454.1255805	5.85	0.0181
sal*sal*conc*conc	1	533.0038258	533.0038258	6.86	0.0107
sal*sal*con*con*conc	1	457.7405100	457.7405100	5.89	0.0176

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-1.29620690	1.63674524	-0.79	0.4309
sal	15.88225904	4.48228820	3.54	0.0007
sal*sal	-0.78664232	0.22435002	-3.51	0.0008
sal*conc*conc	-11.60075309	4.46006013	-2.60	0.0112
sal*conc*conc*conc	3.82494631	1.58203994	2.42	0.0181
sal*sal*conc*conc	0.58671237	0.22399595	2.62	0.0107
sal*sal*con*con*conc	-0.19284819	0.07944855	-2.43	0.0176

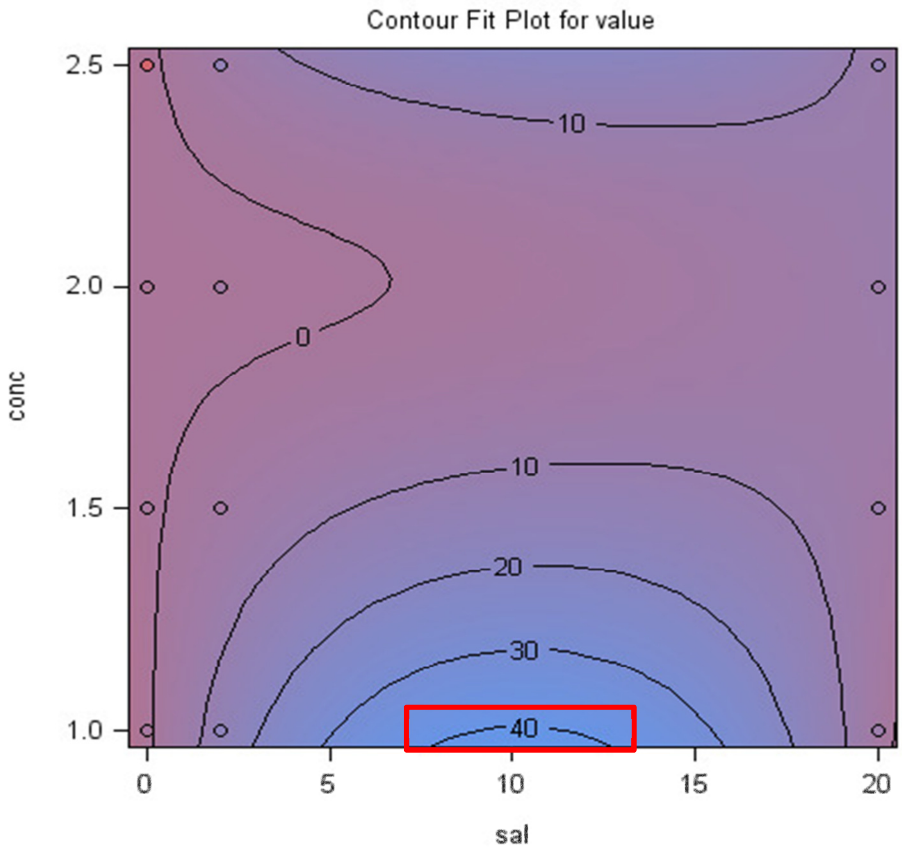


Figure 4.2. The Contour Fit Plot from the GLMSelect Program Showing the Growth Curves for Phosphoric Acid and Salinity Levels.

The Response Surface model shows the predicted interaction between all possible combinations of salinity and phosphoric acid on the ranges that were tested. This figure also indicates that a 1x concentration of phosphoric acid and salinity of 10 ppt would produce the maximum growth of plant biomass in a 30-day period, as indicated by the red box. The model does appear to have a saddle shape to it indicating that both low and high salinity may have negative effects on plant growth, and lower phosphoric acid may encourage plant growth. The surface model shows a peak growth rate of 40 grams in the 30-day period.

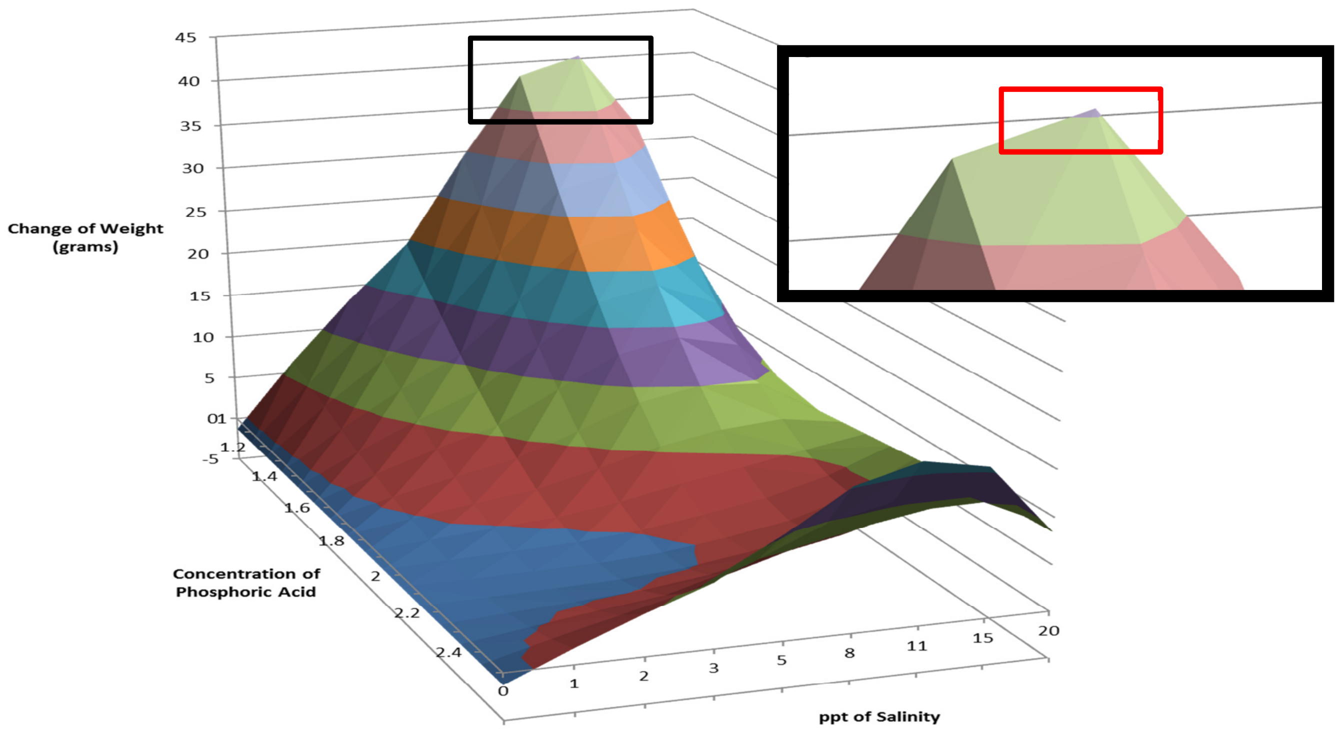


Figure 4.3. The Response Surface Model from data obtained by the SAS® GLMSeries and plotted in Excel® for a 30-day period

Although the analysis of the plants' mortality did not return any significant results, the salinity*salinity did have a Pr value of 0.0880 with an F-value of 2.98, which shows that there could be some interaction suggesting very low or very high salinities may increase mortality. The Contour Fit Plot (Figure 4.4) shows an area of interest where the mortality rate is predicted to be 80%. This zone is between 1.25x and 1.5x concentration of phosphoric acid and 7 and 13 ppt of salinity, as shown in the box in Figure 4.4.

Table 4.5. The Results of the GLMSelect Program for Mortality

Source	DF	Type I SS	Mean Square	F Value	Pr > F
sal	1	0.02524038	0.02524038	0.18	0.6704
sal*sal	1	0.41225962	0.41225962	2.98	0.0880
conc	1	0.10208333	0.10208333	0.74	0.3929
conc*conc	1	0.09375000	0.09375000	0.68	0.4128
conc*conc*conc	1	0.25208333	0.25208333	1.82	0.1808
sal*conc	1	0.02748397	0.02748397	0.20	0.6570
sal*conc*conc	1	0.04172390	0.04172390	0.30	0.5844
sal*conc*conc*conc	1	0.02116529	0.02116529	0.15	0.6967
sal*sal*conc	1	0.00168269	0.00168269	0.01	0.9125
sal*sal*conc*conc	1	0.02077610	0.02077610	0.15	0.6994
sal*sal*con*con*conc	1	0.03300137	0.03300137	0.24	0.6266

Source	DF	Type III SS	Mean Square	F Value	Pr > F
sal	1	0.03107774	0.03107774	0.22	0.6368
sal*sal	1	0.03707494	0.03707494	0.27	0.6061
conc	1	0.04407358	0.04407358	0.32	0.5740
conc*conc	1	0.05081301	0.05081301	0.37	0.5462
conc*conc*conc	1	0.05625000	0.05625000	0.41	0.5255
sal*conc	1	0.03371994	0.03371994	0.24	0.6229
sal*conc*conc	1	0.03127548	0.03127548	0.23	0.6357
sal*conc*conc*conc	1	0.02859591	0.02859591	0.21	0.6506
sal*sal*conc	1	0.03944959	0.03944959	0.29	0.5948
sal*sal*conc*conc	1	0.03628384	0.03628384	0.26	0.6100
sal*sal*con*con*conc	1	0.03300137	0.03300137	0.24	0.6266

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-1.749999999	3.58031261	-0.49	0.6263
sal	-1.326388890	2.79900047	-0.47	0.6368
sal*sal	0.069444445	0.13416961	0.52	0.6061
conc	3.874999998	6.86656228	0.56	0.5740
conc*conc	-2.499999999	4.12581161	-0.61	0.5462
conc*conc*conc	0.500000000	0.78426996	0.64	0.5255
sal*conc	2.649768521	5.36810976	0.49	0.6229
sal*conc*conc	-1.533333335	3.22545819	-0.48	0.6357
sal*conc*conc*conc	0.278703704	0.61312299	0.45	0.6506
sal*sal*conc	-0.137384259	0.25731942	-0.53	0.5948
sal*sal*conc*conc	0.079166667	0.15461178	0.51	0.6100
sal*sal*con*con*conc	-0.014351852	0.02938994	-0.49	0.6266

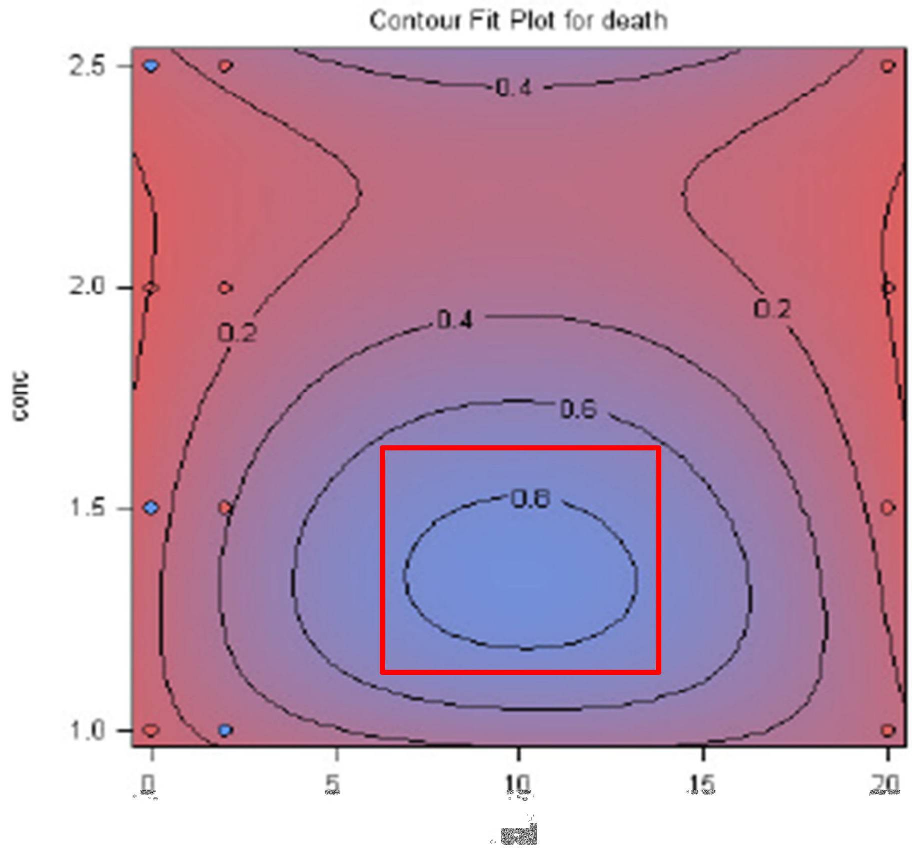


Figure 4.4. The Contour Fit Plot from the GLMSelect Program Showing the Mortality Rates for Phosphoric Acid and Salinity Levels

CHAPTER 5. DISCUSSION AND CONCLUSIONS

Overall, this study showed that not only can sea oats grow in a hydroponic system, but also given the right fertilizer and salinity, they can thrive. As shown in the results, the biomass growth varied greatly, but the overall growth was a positive trend. The two systems that showed only biomass loss were not repeatable in other trials. The loss of biomass could be partially the result of a multitude of other factors, such as lack of airflow, or the plants may not have fully recovered from the shock of the transplanting.

This study does support the idea that sea oats are possibly not only resistant to salinity but may even be dependent on the salt spray from the ocean for nutrients. The group that had the most plants lose biomass was 0 ppt of salinity. Without the micronutrients, it is possible that the sea oats were not able to flourish in the systems.

As shown by the SAS® GLMSeries, salinity did have a significant effect on the growth of the plants, but phosphorus concentration was not statistically significant. Because the Type III Sum of Squares came back with all significant values, we can conclude that the equation will be cubic. The estimates from these equations can then be used in the Response Surface Model to map all possible interactions within the range of the variables tested in this study. In both the Contour Fit Plot and Response Surface Model, the ideal combination of salinity and phosphoric acid can be found. Both of these charts show 10 ppt and concentration of 1x of phosphoric acid would produce a growth rate of 40 grams within 30 days. The Response Surface does have a saddle shape to it, indicating that it is possible that an even larger concentration of phosphoric acid within the same salinity range could also produce a high growth rate; however, to keep costs minimal, this would be unnecessary.

As shown above in Figure 4.4, the area of interest for mortality rate is between 1.25x and 1.5x the concentration of phosphoric acid and 7 and 13 ppt of salinity. This area does show predicted growth in the other models, which could indicate that plants could survive in this environment, but the mortality rate would be higher than desired. The predicted mortality rate for the ideal concentrations is 0% with a mortality rate increase of 20% on the ends of the range. Further testing is needed to verify the predicted growth and mortality rate, as only two salinity levels were tested.

It was demonstrated that aeration of the saline medium, which provided increased dissolved oxygen levels, prevented the fibrous roots of the sea oat plants from becoming water logged. This additional oxygen is the primary difference identified in this experiment that provided successful sea oat growth in a hydroponic system. Additional research is needed to quantify the optimum level of dissolved oxygen corresponding to maximum sea oat growth, potentially minimizing the costs of the artificial aeration. It is expected that an optimum level of dissolved oxygen will be found, with no additional plant growth effects occurring beyond this level.

The 2012 Coastal Master Plan includes five types of projects that are plant dependent: Bank Stabilization, Ridge Restoration, Shoreline Protection, Barrier Island Restoration, and Marsh Creation. It is apparent that plants are in demand for restoration projects. The findings in this report could allow for sea oats or other coastal plants to be produced in a more efficient method with a system that can be converted to a large-scale commercial set-up.

Overall, this study showed that sea oats, *Uniola paniculata*, could be grown hydroponically and suggest some techniques and concentrations of salinity and nutrients that could optimize the process. Further study would be helpful to identify more accurately the ideal techniques and conditions to culture these important plants. Furthermore, the hydroponic techniques could also be used to acclimate plants to expected field conditions by altering salinity or nutrient levels in a controlled fashion. In this way, optimal production and propagation for sea oats in real world conditions can be performed to enhance the success of coastal restoration projects.

REFERENCES

Aldana, M. E. (2005). *Effect of phosphorus and potassium fertility on fruit quality and growth of Tabasco pepper (Capsicum frutescens) in hydroponic culture* (Master's thesis, Louisiana State University).

Baker, R. (1972). *Use of Fertilizer to Increase Vigor of Sea Oats and Bitter Panicum* (Master's Thesis, Texas Tech University).

Bell, H. L., & O'Leary, J. W. (2003). Effects of salinity on growth and cation accumulation of Sporobolus virginicus (Poaceae). *American Journal of Botany*,*90*(10), 1416-1424.

Bertrand-Garcia, S. E., Knott, C. A., Baisakh, N., Subudhi, P. K., Harrison, S. A., Materne, M. D., & Utomo, H. (2012). Selection of genetically diverse sea oats lines with improved performance for coastal restoration in the northern Gulf of Mexico. *Euphytica*, *185*(1), 103-117.

Boyd, C. A. and S. G. Hall, 2012. Cost estimates for shoreline erosion products in the Northern Gulf of Mexico. Bays and Bayous Symposium, Habitat Management and Restoration, Nov 2012, Biloxi Miss. http://masgc.org/bb2012/Abstractspdf/HM_PDFs/HM_Boyd_Chris_abstract2_final.pdf

Coastal Erosion: Facts and Figures. (2012) *Restore or Retreat*. Retrieved July 7, 2013, from http://www.restoreorretreat.org/la_erosion_facts.php

Coastal Protection and Restoration Authority of Louisiana. (2012). 2012 Coastal Master Plan. Baton Rouge, La. 190 p.

Dahl, B. E., Fall, B. A., Lohse, A., & Appan, S. G. (1975). Construction and Stabilization of Coastal Foredunes with Vegetation: Padre Island, Texas. GULF UNIVERSITIES RESEARCH CONSORTIUM HOUSTON TX.

Delgado, M., Zúñiga-Feest, A., Alvear, M., & Borie, F. (2013). The effect of phosphorus on cluster-root formation and functioning of Embothrium coccineum (R. et J. Forst.). *Plant and Soil*, 1-9.

Essential Elements for Plant Growth. (2009). *Hydroponics*. Retrieved July 7, 2013, from http://www.soils.wisc.edu/courses/soils326/hydropon.htm

Feagin, R. A., Koske, R. E., Gemma, J. N., & Williams, A. M. (2013). Restoration of Sea Oats (Uniola paniculata) with Mycorrhizae on Galveston Island. A report of the Coastal Coordination Council pursuant to National Oceanic and Atmospheric Administration Aw ard No. NA07NOS4190144.

Gorham, E. (1958). Soluble salts in dune sands from Blakeney Point in Norfolk.*The Journal of Ecology*, 373-379.

Gormally, C. L., & Donovan, L. A. (2010). Responses of Uniola paniculata L.(Poaceae), an essential dune-building grass, to complex changing environmental gradients on the coastal dunes. *Estuaries and Coasts*, *33*(5), 1237-1246.

Green, D. G., & Warder, F. G. (1973). Accumulation of damaging concentrations of phosphorus by leaves of Selkirk wheat. *Plant and Soil*, *38*(3), 567-572.

Hendricks, R. C., & Bushnell, D. M. (2008, February). Halophytes energy feedstocks: back to our roots. In *12th International Symposium on Transport Phenomena and Dynamics of Rotating Machinery, Honolulu, Hawaii*.

Hester, M. W., & Mendelssohn, I. A. (1987). Seed production and germination response of four Louisiana populations of Uniola paniculata (Gramineae).*American Journal of Botany*, 1093-1101.

Hester, M. W., & Mendelssohn, I. A. (1989). Water relations and growth responses of Uniola paniculata (sea oats) to soil moisture and water-table depth. *Oecologia*, *78*(3), 289-296.

Hester, M. W., & Mendelssohn, I. A. (1991). Expansion patterns and soil physicochemical characterization of three Louisiana populations of Uniola paniculata (sea oats). *Journal of Coastal Research*, 387-401.

Hill, K. (2001). Sea oats. Smithsonian Marine Station.

Koyro, H. W., Hussain, T., Huchzermeyer, B., & Khan, M. A. (2013). Photosynthetic and growth responses of a perennial halophytic grass *Panicum turgidum* to increasing NaCl concentrations. *Environmental and Experimental Botany*.

Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority. (1998). Coast 2050: Toward a Sustainable Coastal Louisiana. Louisiana Department of Natural Resources. Baton Rouge, La. 161 p

Louw-Gaume, A. E., Rao, I. M., Gaume, A. J., & Frossard, E. (2010). A comparative study on plant growth and root plasticity responses of two Brachiaria forage grasses grown in nutrient solution at low and high phosphorus supply. *Plant and Soil*, *328*(1-2), 155-164.

Marschner, H. (2012). Marschner's Mineral Nutrition of Higher Plants. 3rd edn. Academic, London.

McCauley, A., Jones, C., & Jacobsen, J. (2009). Plant nutrient functions and deficiency and toxicity symptoms. Nutrient Management Module, 9, 1.

Miller, D. L., Yager, L., Thetford, M., & Schneider, M. (2003). Potential use of Uniola paniculata rhizome fragments for dune restoration. *Restoration Ecology*,*11*(3), 359-369.

Nabukalu, P. (2013). *Development of an Efficient Sea Oats Breeding Program for Coastal Restoration* (Doctoral dissertation, Louisiana State University).

Nabukalu, P., & Knott, C. A. (2013). Effect of Sea Oats (Uniola paniculata) Plant Size on Survival and Performance at Beaches with Low Dune Profiles.*Ecological Restoration*, *31*(1), 12-16.

Nabukalu, P., & Knott, C. A. (2013). Effect of Seed Storage Environment on Sea Oats (Uniola paniculata) Germination. *Ecological Restoration*, *31*(1), 16-19.

Norden, D. S., Warren, S. L., Blazich, F. A., & Nash, D. L. (2008). Nitrogen nutrition of southern seaoats (Uniola paniculata) grown in the float system.*Journal of Environmental Horticulture*, *26*(2), 80.

Pessarakli, M., Harivandi, M. A., Kopec, D. M., & Ray, D. T. (2012). Growth responses and nitrogen uptake by saltgrass (Distichlis spicata L.), a halophytic plant species, under salt stress, using the 15 N technique. *International Journal of Agronomy*, *2012*.

Piehler, M. F., & Smyth, A. R. (2011). Habitat-specific distinctions in estuarine denitrification affect both ecosystem function and services. *Ecosphere*, *2*(1), art12.

LSU AgCenter. Plant Guide for Louisiana Beaches. 2013.

Ricciuti, E.R. (1984). Elegant builder of southern dunes. Natioal Audubon Society. 86:48-53.

Seneca, E. D. (1972). Germination and seedling response of Atlantic and Gulf coasts populations of Uniola paniculata. *American Journal of Botany*, 290-296.

Shadow, R.A. (2007). Plant fact sheet for Sea Oats. USDA-Natural Resources Conservation Service, East Texas Plant Material Center, Nacogdoches, TX 75964.

Sylvia, D. M., Alagely, A. K., Kane, M. E., & Philman, N. L. (2003). Compatible host/mycorrhizal fungus combinations for micropropagated sea oats.*Mycorrhiza*, *13*(4), 177-183.

Thiyagarajan, G., Umadevi, R., & Ramesh, K. (2007). Hydroponics. *Science Tech Entrepreneur. January*.

Yoneyama, K., Xie, X., Kisugi, T., Nomura, T., & Yoneyama, K. (2013). Nitrogen and phosphorus fertilization negatively affects strigolactone production and exudation in sorghum. *Planta*, 1-10.

APPENDIX A. SAS® PROGRAMMING

```
dm'log;clear;output;clear;results;clear';
Title "Data from Sea Oats - Stefanie Gilliam";
options nodate nocenter pageno=1 ls=168 ps=60
       FORMCHAR="|----|+|---+=|-/\<>*";
ods html style=minimal body="Stefanie Gilliam OUTPUT.html";

data one two;
input treat value rep sal conc trial death;
  output two;
  if death=1 then delete; output one;
datalines;
1   -2.76   1   0   1   1   0
2   -1.87   1   0   1.5   1   0
3   0.2    1   0   2   1   0
4   0.5      1   0   2.5   1   0
5   26.1   1   2   1   1   0
6   -3.5   1   2   1.5   1   1
7   -4.2   1   2   2   1   0
8   7.2      1   2   2.5   1   1
9   0.8      1   20   1   1   0
10   -1.7   1   20   1.5   1   1
11   0.1      1   20   2   1   0
12   3.8   1   20   2.5   1   0
13   -0.93   2   0   1   1   0
14   -8.69   2   0   1.5   1   0
15   -0.5   2   0   2   1   0
16   -2.8   2   0   2.5   1   0
17   8.5     2   2   1   1   0
18   -2.3   2   2   1.5   1   1
19   -0.1   2   2   2   1   0
20   18.1   2   2   2.5   1   0
21   -0.2   2   20   1   1   1
22   9.7      2   20   1.5   1   0
23   4      2   20   2   1   0
24   1.2      2   20   2.5   1   0
25   -6.69   3   0   1   1   0
26   -8.56   3   0   1.5   1   0
27   1.3      3   0   2   1   0
28   -3.8   3   0   2.5   1   0
29   11.8   3   2   1   1   0
30   7.8      3   2   1.5   1   0
31   5.9      3   2   2   1   0
32   -21.5   3   2   2.5   1   1
```

33	2	3	20	1	1	0
34	-1	3	20	1.5	1	0
35	1.2	3	20	2	1	0
36	0.3	3	20	2.5	1	1
37	4.79	4	0	1	1	1
38	-0.39	4	0	1.5	1	0
39	17.6	4	0	2	1	0
40	-0.2	4	0	2.5	1	0
41	-5.8	4	2	1	1	1
42	8.5	4	2	1.5	1	0
43	0.5	4	2	2	1	0
44	2	4	2	2.5	1	0
45	-0.6	4	20	1	1	0
46	7.2	4	20	1.5	1	0
47	3.1	4	20	2	1	0
48	-1.3	4	20	2.5	1	0
49	-6.1	1	0	1	2	0
50	2.7	1	0	1.5	2	0
51	-3.2	1	0	2	2	0
52	8.7	1	0	2.5	2	0
53	17.2	1	2	1	2	0
54	-11.6	1	2	1.5	2	1
55	-11.3	1	2	2	2	1
56	-8.9	1	2	2.5	2	0
57	-1.2	1	20	1	2	0
58	8.4	1	20	1.5	2	0
59	5.2	1	20	2	2	0
60	13.9	1	20	2.5	2	0
61	4.9	2	0	1	2	0
62	13.6	2	0	1.5	2	0
63	-8.4	2	0	2	2	0
64	-2.7	2	0	2.5	2	0
65	-0.4	2	2	1	2	0
66	4.3	2	2	1.5	2	0
67	-18.1	2	2	2	2	0
68	1.8	2	2	2.5	2	0
69	-2.9	2	20	1	2	1
70	9.6	2	20	1.5	2	0
71	9.9	2	20	2	2	0
72	6.6	2	20	2.5	2	0
73	29.4	3	0	1	2	0
74	0.3	3	0	1.5	2	0
75	-33.1	3	0	2	2	0
76	-24.4	3	0	2.5	2	0
77	15.5	3	2	1	2	0
78	-2	3	2	1.5	2	0

```
79   1.7      3   2   2   2   0
80   1.9      3   2   2.5   2   0
81   6.4      3   20   1   2   0
82   16      3   20   1.5   2   0
83   12.3   3   20   2   2   0
84   26.5   3   20   2.5   2   0
85   0.5      4   0   1   2   0
86   -13.6   4   0   1.5   2   1
87   -2.2   4   0   2   2   0
88   1.8      4   0   2.5   2   1
89   -7.4   4   2   1   2   1
90   2.8      4   2   1.5   2   0
91   4.1      4   2   2   2   0
92   12.6   4   2   2.5   2   0
93   7      4   20   1   2   0
94   8.1      4   20   1.5   2   0
95   6.5      4   20   2   2   0
96   12.3   4   20   2.5   2   0
;
proc sort data=one out=onesort; by sal conc;
run;

PROC IML;
   RESET PRINT;
   A={0 , 2 , 20};
   ORPOL = ORPOL(A,2);
   multipliers = orpol`;
RUN;

Proc mixed data=one covtest;
   title2 'Proc mixed';
   Class sal conc trial ;
   Model value = sal conc conc*sal / htype=3 outp=residS;
   random trial trial*sal*conc;
   lsmeans sal conc sal*conc / adjust = tukey pdiff cl;
   contrast 'sal line' sal  -0.470757  -0.342368  0.8131249;
   contrast 'sal quad' sal  0.6671244  -0.741249  0.0741249;
   contrast 'sal cheat' sal  -2  1  1;
   contrast 'conc line' conc -3  -1   1  3;
   contrast 'conc quad' conc  1  -1  -1  1;
   contrast 'conc cube' conc -1   3  -3  1;
   ods output diffs=ppp lsmeans=mmm;
  *ods exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=0.05,sort=yes);
```

```
RUN;


proc univariate data=residS plot normal;
  title2 'Proc Univariate';
  var resid;
run;

proc print data=mmm;
  title2 'LSMeans';
run;

Proc rsreg data=one;
  title2 'Proc RSreg';
  Model value = sal conc;
run;

Proc reg data=one;
  title2 'Proc RSreg';
  Model value = sal conc;
run;

Proc glmselect data=one;
  title2 'Proc GLMSelect';
  Model value = sal sal*sal conc conc*conc conc*conc*conc
       sal*conc sal*conc*conc sal*conc*conc*conc
       sal*sal*conc sal*sal*conc*conc sal*sal*conc*conc*conc /
       selection=backward select=sl slentry=0.05 slstay=0.05;
run;

Proc glm data=one;
  title2 'Proc GLM';
  Model value = sal sal*sal sal*conc*conc sal*conc*conc*conc
       sal*sal*conc*conc sal*sal*conc*conc*conc;
run;

Proc glm data=one;
  title2 'Proc GLM';
  Model value = sal sal*sal conc conc*conc conc*conc*conc
       sal*conc sal*conc*conc sal*conc*conc*conc
       sal*sal*conc sal*sal*conc*conc sal*sal*conc*conc*conc;
run;

Proc glm data=two;
  title2 'Proc GLM';
  Model death = sal sal*sal conc conc*conc conc*conc*conc
```

```
      sal*conc sal*conc*conc sal*conc*conc*conc
      sal*sal*conc sal*sal*conc*conc sal*sal*conc*conc*conc;
run;

Proc glmselect data=two;
  title2 'Proc GLMSelect';
  Model death = sal sal*sal conc conc*conc conc*conc*conc
      sal*conc sal*conc*conc sal*conc*conc*conc
      sal*sal*conc sal*sal*conc*conc sal*sal*conc*conc*conc /
      selection=backward select=sl slentry=0.05 slstay=0.05;
run;

Proc rsreg data=two;
  title2 'Proc RSreg';
  Model death = sal conc;
run;

/*

/*
proc means data=onesort ;
  by  sal conc ;
  var value;
  output out=onemeans n=n mean=mean var=var;
run;
proc print data=onemeans;
  title 'listing of means';
run;
proc plot data=onemeans; title 'plot of mean';
  plot mean*sal=conc;
run;
proc univariate data=reside plot normal;
  var resid;
run;
*/

ods html close;

run;
quit;
```

APPENDIX B. SAS® STATISTICAL OUTPUT

Data from Sea Oats - Stefanie Gilliam

A 3 rows 1 col (numeric)

0
2
20

ORPOL 3 rows 3 cols (numeric)

0.5773503	-0.470757	0.6671244
0.5773503	-0.342368	-0.741249
0.5773503	0.8131249	0.0741249

multipliers 3 rows 3 cols (numeric)

0.5773503 0.5773503 0.5773503 -0.470757 -0.342368 0.8131249 0.6671244 -0.741249 0.0741249

Data from Sea Oats - Stefanie Gilliam
Proc mixed

The Mixed Procedure

Model Information	
Data Set	WORK.ONE
Dependent Variable	value
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Containment

Class Level Information		
Class	**Levels**	**Values**
sal	3	0 2 20
conc	4	1 1.5 2 2.5
trial	2	1 2

Dimensions	
Covariance Parameters	3
Columns in X	20
Columns in Z	26
Subjects	1
Max Obs Per Subject	81

Number of Observations	
Number of Observations Read	81
Number of Observations Used	81
Number of Observations Not Used	0

Iteration History			
Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	520.24796004	
1	3	517.07418520	0.00017610
2	1	517.03691395	0.00000353
3	1	517.03621523	0.00000000

Convergence criteria met.

Covariance Parameter Estimates				
Cov Parm	Estimate	Standard Error	Z Value	Pr > Z
trial	0	.	.	.
sal*conc*trial	20.6391	16.5352	1.25	0.1060
Residual	66.8796	12.4410	5.38	<.0001

Fit Statistics	
-2 Res Log Likelihood	517.0
AIC (smaller is better)	521.0
AICC (smaller is better)	521.2
BIC (smaller is better)	518.4

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
sal	2	11	3.25	0.0777
conc	3	11	0.92	0.4630
sal*conc	6	11	0.83	0.5724

Contrasts				
Label	Num DF	Den DF	F Value	Pr > F
sal line	1	11	2.73	0.1265
sal quad	1	11	3.59	0.0847
sal cheat	1	11	6.42	0.0278
conc line	1	11	1.02	0.3335
conc quad	1	11	0.92	0.3593
conc cube	1	11	0.73	0.4120

Least Squares Means										
Effect	**sal**	**conc**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**	**Alpha**	**Lower**	**Upper**
sal	**0**		-1.2601	2.2165	11	-0.57	0.5811	0.05	-6.1386	3.6185
sal	**2**		5.3111	2.3381	11	2.27	0.0442	0.05	0.1649	10.4573
sal	**20**		6.0706	2.2374	11	2.71	0.0202	0.05	1.1460	10.9951
conc		**1**	5.9144	2.6438	11	2.24	0.0469	0.05	0.09540	11.7335
conc		**1.5**	4.2050	2.6643	11	1.58	0.1428	0.05	-1.6591	10.0690
conc		**2**	0.04101	2.5240	11	0.02	0.9873	0.05	-5.5143	5.5963
conc		**2.5**	3.3351	2.6257	11	1.27	0.2302	0.05	-2.4440	9.1141
sal*conc	**0**	**1**	2.2266	4.4695	11	0.50	0.6282	0.05	-7.6106	12.0638
sal*conc	**0**	**1.5**	-0.03341	4.4695	11	-0.01	0.9942	0.05	-9.8706	9.8038
sal*conc	**0**	**2**	-3.5375	4.3220	11	-0.82	0.4305	0.05	-13.0501	5.9751
sal*conc	**0**	**2.5**	-3.6960	4.4695	11	-0.83	0.4258	0.05	-13.5332	6.1413
sal*conc	**2**	**1**	13.1167	4.6332	11	2.83	0.0163	0.05	2.9192	23.3142
sal*conc	**2**	**1.5**	4.5544	4.8921	11	0.93	0.3718	0.05	-6.2130	15.3219
sal*conc	**2**	**2**	-1.6270	4.4695	11	-0.36	0.7227	0.05	-11.4642	8.2102
sal*conc	**2**	**2.5**	5.2003	4.7005	11	1.11	0.2922	0.05	-5.1455	15.5461
sal*conc	**20**	**1**	2.4000	4.6332	11	0.52	0.6147	0.05	-7.7975	12.5975
sal*conc	**20**	**1.5**	8.0938	4.4695	11	1.81	0.0975	0.05	-1.7434	17.9311
sal*conc	**20**	**2**	5.2875	4.3220	11	1.22	0.2467	0.05	-4.2251	14.8001
sal*conc	**20**	**2.5**	8.5009	4.4695	11	1.90	0.0837	0.05	-1.3363	18.3381

Differences of Least Squares Means																
Effect	**sal**	**conc**	**_sal**	**_conc**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**	**Adjustment**	**Adj P**	**Alpha**	**Lower**	**Upper**	**Adj Lower**	**Adj Upper**
sal	**0**		**2**		-6.5712	3.2218	11	-2.04	0.0661	Tukey-Kramer	0.1487	0.05	-13.6623	0.5199	-15.2727	2.1304
sal	**0**		**20**		-7.3306	3.1495	11	-2.33	0.0400	Tukey-Kramer	0.0935	0.05	-14.2625	-0.3987	-15.8368	1.1756
sal	**2**		**20**		-0.7595	3.2362	11	-0.23	0.8188	Tukey-Kramer	0.9702	0.05	-7.8823	6.3634	-9.4999	7.9810
conc		**1**		**1.5**	1.7095	3.7534	11	0.46	0.6576	Tukey-Kramer	0.9672	0.05	-6.5518	9.9707	-9.5863	13.0053
conc		**1**		**2**	5.8734	3.6552	11	1.61	0.1364	Tukey-Kramer	0.4139	0.05	-2.1716	13.9184	-5.1268	16.8736
conc		**1**		**2.5**	2.5794	3.7261	11	0.69	0.5031	Tukey-Kramer	0.8979	0.05	-5.6218	10.7805	-8.6343	13.7930
conc		**1.5**		**2**	4.1640	3.6700	11	1.13	0.2807	Tukey-Kramer	0.6771	0.05	-3.9137	12.2416	-6.8808	15.2087
conc		**1.5**		**2.5**	0.8699	3.7407	11	0.23	0.8204	Tukey-Kramer	0.9953	0.05	-7.3632	9.1030	-10.3875	12.1273
conc		**2**		**2.5**	-3.2941	3.6421	11	-0.90	0.3851	Tukey-Kramer	0.8029	0.05	-11.3102	4.7221	-14.2548	7.6666
sal*conc	**0**	**1**	**0**	**1.5**	2.2600	6.3208	11	0.36	0.7274	Tukey-Kramer	1.0000	0.05	-11.6519	16.1720	-23.2736	27.7937

sal*conc	**0**	**1**	**0**	**2**	5.7641	6.2174	11	0.93	0.3738	Tukey-Kramer	0.9968	0.05	-7.9202	19.4484	-19.3518	30.8800
sal*conc	**0**	**1**	**0**	**2.5**	5.9226	6.3208	11	0.94	0.3689	Tukey-Kramer	0.9965	0.05	-7.9894	19.8345	-19.6111	31.4562
sal*conc	**0**	**1**	**2**	**1**	-10.8901	6.4376	11	-1.69	0.1188	Tukey-Kramer	0.8408	0.05	-25.0591	3.2789	-36.8955	15.1154
sal*conc	**0**	**1**	**2**	**1.5**	-2.3278	6.6264	11	-0.35	0.7320	Tukey-Kramer	1.0000	0.05	-16.9124	12.2567	-29.0959	24.4403
sal*conc	**0**	**1**	**2**	**2**	3.8536	6.3208	11	0.61	0.5545	Tukey-Kramer	0.9999	0.05	-10.0584	17.7655	-21.6800	29.3872
sal*conc	**0**	**1**	**2**	**2.5**	-2.9737	6.4862	11	-0.46	0.6555	Tukey-Kramer	1.0000	0.05	-17.2498	11.3024	-29.1757	23.2283
sal*conc	**0**	**1**	**20**	**1**	-0.1734	6.4376	11	-0.03	0.9790	Tukey-Kramer	1.0000	0.05	-14.3424	13.9956	-26.1788	25.8320
sal*conc	**0**	**1**	**20**	**1.5**	-5.8672	6.3208	11	-0.93	0.3732	Tukey-Kramer	0.9967	0.05	-19.7792	8.0447	-31.4009	19.6664
sal*conc	**0**	**1**	**20**	**2**	-3.0609	6.2174	11	-0.49	0.6322	Tukey-Kramer	1.0000	0.05	-16.7452	10.6234	-28.1768	22.0550
sal*conc	**0**	**1**	**20**	**2.5**	-6.2743	6.3208	11	-0.99	0.3422	Tukey-Kramer	0.9944	0.05	-20.1862	7.6377	-31.8079	19.2594
sal*conc	**0**	**1.5**	**0**	**2**	3.5041	6.2174	11	0.56	0.5843	Tukey-Kramer	1.0000	0.05	-10.1802	17.1884	-21.6118	28.6200
sal*conc	**0**	**1.5**	**0**	**2.5**	3.6626	6.3208	11	0.58	0.5740	Tukey-Kramer	1.0000	0.05	-10.2494	17.5745	-21.8711	29.1962
sal*conc	**0**	**1.5**	**2**	**1**	-13.1501	6.4376	11	-2.04	0.0658	Tukey-Kramer	0.6642	0.05	-27.3191	1.0189	-39.1555	12.8553
sal*conc	**0**	**1.5**	**2**	**1.5**	-4.5879	6.6264	11	-0.69	0.5031	Tukey-Kramer	0.9997	0.05	-19.1724	9.9967	-31.3560	22.1802
sal*conc	**0**	**1.5**	**2**	**2**	1.5936	6.3208	11	0.25	0.8056	Tukey-Kramer	1.0000	0.05	-12.3184	15.5055	-23.9401	27.1272
sal*conc	**0**	**1.5**	**2**	**2.5**	-5.2337	6.4862	11	-0.81	0.4368	Tukey-Kramer	0.9990	0.05	-19.5098	9.0424	-31.4357	20.9683
sal*conc	**0**	**1.5**	**20**	**1**	-2.4334	6.4376	11	-0.38	0.7126	Tukey-Kramer	1.0000	0.05	-16.6024	11.7356	-28.4388	23.5720
sal*conc	**0**	**1.5**	**20**	**1.5**	-8.1273	6.3208	11	-1.29	0.2249	Tukey-Kramer	0.9648	0.05	-22.0392	5.7847	-33.6609	17.4064
sal*conc	**0**	**1.5**	**20**	**2**	-5.3209	6.2174	11	-0.86	0.4104	Tukey-Kramer	0.9983	0.05	-19.0052	8.3634	-30.4368	19.7950
sal*conc	**0**	**1.5**	**20**	**2.5**	-8.5343	6.3208	11	-1.35	0.2041	Tukey-Kramer	0.9523	0.05	-22.4462	5.3776	-34.0679	16.9993
sal*conc	**0**	**2**	**0**	**2.5**	0.1585	6.2174	11	0.03	0.9801	Tukey-Kramer	1.0000	0.05	-13.5259	13.8428	-24.9574	25.2743
sal*conc	**0**	**2**	**2**	**1**	-16.6542	6.3361	11	-2.63	0.0235	Tukey-Kramer	0.3631	0.05	-30.5997	-2.7086	-42.2495	8.9412
sal*conc	**0**	**2**	**2**	**1.5**	-8.0919	6.5278	11	-1.24	0.2409	Tukey-Kramer	0.9723	0.05	-22.4595	6.2756	-34.4619	18.2780
sal*conc	**0**	**2**	**2**	**2**	-1.9105	6.2174	11	-0.31	0.7644	Tukey-Kramer	1.0000	0.05	-15.5948	11.7738	-27.0264	23.2054
sal*conc	**0**	**2**	**2**	**2.5**	-8.7378	6.3855	11	-1.37	0.1985	Tukey-Kramer	0.9483	0.05	-22.7922	5.3166	-34.5329	17.0573
sal*conc	**0**	**2**	**20**	**1**	-5.9375	6.3361	11	-0.94	0.3688	Tukey-Kramer	0.9965	0.05	-19.8831	8.0081	-31.5329	19.6579
sal*conc	**0**	**2**	**20**	**1.5**	-11.6313	6.2174	11	-1.87	0.0882	Tukey-	0.7557	0.05	-25.3157	2.0530	-36.7472	13.4845

										Kramer						
sal*conc	**0**	**2**	**20**	**2**	-8.8250	6.1122	11	-1.44	0.1767	Tukey-Kramer	0.9293	0.05	-22.2779	4.6279	-33.5161	15.8661
sal*conc	**0**	**2**	**20**	**2.5**	-12.0384	6.2174	11	-1.94	0.0789	Tukey-Kramer	0.7216	0.05	-25.7227	1.6459	-37.1543	13.0775
sal*conc	**0**	**2.5**	**2**	**1**	-16.8126	6.4376	11	-2.61	0.0242	Tukey-Kramer	0.3705	0.05	-30.9816	-2.6436	-42.8181	9.1928
sal*conc	**0**	**2.5**	**2**	**1.5**	-8.2504	6.6264	11	-1.25	0.2390	Tukey-Kramer	0.9715	0.05	-22.8349	6.3341	-35.0185	18.5177
sal*conc	**0**	**2.5**	**2**	**2**	-2.0690	6.3208	11	-0.33	0.7496	Tukey-Kramer	1.0000	0.05	-15.9809	11.8430	-27.6026	23.4647
sal*conc	**0**	**2.5**	**2**	**2.5**	-8.8963	6.4862	11	-1.37	0.1975	Tukey-Kramer	0.9476	0.05	-23.1724	5.3799	-35.0983	17.3058
sal*conc	**0**	**2.5**	**20**	**1**	-6.0960	6.4376	11	-0.95	0.3640	Tukey-Kramer	0.9962	0.05	-20.2650	8.0730	-32.1014	19.9095
sal*conc	**0**	**2.5**	**20**	**1.5**	-11.7898	6.3208	11	-1.87	0.0890	Tukey-Kramer	0.7585	0.05	-25.7017	2.1221	-37.3234	13.7438
sal*conc	**0**	**2.5**	**20**	**2**	-8.9835	6.2174	11	-1.44	0.1764	Tukey-Kramer	0.9290	0.05	-22.6678	4.7009	-34.0993	16.1324
sal*conc	**0**	**2.5**	**20**	**2.5**	-12.1969	6.3208	11	-1.93	0.0798	Tukey-Kramer	0.7251	0.05	-26.1088	1.7151	-37.7305	13.3368
sal*conc	**2**	**1**	**2**	**1.5**	8.5622	6.7379	11	1.27	0.2300	Tukey-Kramer	0.9674	0.05	-6.2677	23.3922	-18.6563	35.7807
sal*conc	**2**	**1**	**2**	**2**	14.7436	6.4376	11	2.29	0.0428	Tukey-Kramer	0.5291	0.05	0.5747	28.9126	-11.2618	40.7491
sal*conc	**2**	**1**	**2**	**2.5**	7.9164	6.6001	11	1.20	0.2556	Tukey-Kramer	0.9778	0.05	-6.6104	22.4431	-18.7456	34.5784
sal*conc	**2**	**1**	**20**	**1**	10.7167	6.5523	11	1.64	0.1302	Tukey-Kramer	0.8642	0.05	-3.7048	25.1381	-15.7521	37.1855
sal*conc	**2**	**1**	**20**	**1.5**	5.0228	6.4376	11	0.78	0.4517	Tukey-Kramer	0.9993	0.05	-9.1462	19.1918	-20.9826	31.0282
sal*conc	**2**	**1**	**20**	**2**	7.8292	6.3361	11	1.24	0.2423	Tukey-Kramer	0.9729	0.05	-6.1164	21.7747	-17.7662	33.4245
sal*conc	**2**	**1**	**20**	**2.5**	4.6158	6.4376	11	0.72	0.4883	Tukey-Kramer	0.9997	0.05	-9.5532	18.7848	-21.3896	30.6212
sal*conc	**2**	**1.5**	**2**	**2**	6.1814	6.6264	11	0.93	0.3709	Tukey-Kramer	0.9966	0.05	-8.4031	20.7660	-20.5867	32.9495
sal*conc	**2**	**1.5**	**2**	**2.5**	-0.6458	6.7844	11	-0.10	0.9259	Tukey-Kramer	1.0000	0.05	-15.5782	14.2865	-28.0523	26.7606
sal*conc	**2**	**1.5**	**20**	**1**	2.1544	6.7379	11	0.32	0.7551	Tukey-Kramer	1.0000	0.05	-12.6755	16.9844	-25.0641	29.3729
sal*conc	**2**	**1.5**	**20**	**1.5**	-3.5394	6.6264	11	-0.53	0.6039	Tukey-Kramer	1.0000	0.05	-18.1239	11.0451	-30.3075	23.2287
sal*conc	**2**	**1.5**	**20**	**2**	-0.7331	6.5278	11	-0.11	0.9126	Tukey-Kramer	1.0000	0.05	-15.1006	13.6345	-27.1030	25.6369
sal*conc	**2**	**1.5**	**20**	**2.5**	-3.9464	6.6264	11	-0.60	0.5635	Tukey-Kramer	0.9999	0.05	-18.5310	10.6381	-30.7145	22.8217
sal*conc	**2**	**2**	**2**	**2.5**	-6.8273	6.4862	11	-1.05	0.3151	Tukey-Kramer	0.9913	0.05	-21.1034	7.4488	-33.0293	19.3748
sal*conc	**2**	**2**	**20**	**1**	-4.0270	6.4376	11	-0.63	0.5444	Tukey-Kramer	0.9999	0.05	-18.1960	10.1420	-30.0324	21.9784
sal*conc	**2**	**2**	**20**	**1.5**	-9.7208	6.3208	11	-1.54	0.1523	Tukey-Kramer	0.9004	0.05	-23.6328	4.1911	-35.2545	15.8128

sal*conc	**2**	**2**	**20**	**2**	-6.9145	6.2174	11	-1.11	0.2898	Tukey-Kramer	0.9869	0.05	-20.5988	6.7698	-32.0304	18.2014
sal*conc	**2**	**2**	**20**	**2.5**	-10.1279	6.3208	11	-1.60	0.1374	Tukey-Kramer	0.8772	0.05	-24.0398	3.7841	-35.6615	15.4058
sal*conc	**2**	**2.5**	**20**	**1**	2.8003	6.6001	11	0.42	0.6795	Tukey-Kramer	1.0000	0.05	-11.7264	17.3270	-23.8617	29.4623
sal*conc	**2**	**2.5**	**20**	**1.5**	-2.8935	6.4862	11	-0.45	0.6642	Tukey-Kramer	1.0000	0.05	-17.1697	11.3826	-29.0956	23.3085
sal*conc	**2**	**2.5**	**20**	**2**	-0.08721	6.3855	11	-0.01	0.9893	Tukey-Kramer	1.0000	0.05	-14.1416	13.9672	-25.8823	25.7079
sal*conc	**2**	**2.5**	**20**	**2.5**	-3.3006	6.4862	11	-0.51	0.6209	Tukey-Kramer	1.0000	0.05	-17.5767	10.9755	-29.5026	22.9014
sal*conc	**20**	**1**	**20**	**1.5**	-5.6938	6.4376	11	-0.88	0.3954	Tukey-Kramer	0.9978	0.05	-19.8628	8.4752	-31.6993	20.3116
sal*conc	**20**	**1**	**20**	**2**	-2.8875	6.3361	11	-0.46	0.6575	Tukey-Kramer	1.0000	0.05	-16.8331	11.0581	-28.4829	22.7079
sal*conc	**20**	**1**	**20**	**2.5**	-6.1009	6.4376	11	-0.95	0.3636	Tukey-Kramer	0.9961	0.05	-20.2699	8.0681	-32.1063	19.9045
sal*conc	**20**	**1.5**	**20**	**2**	2.8063	6.2174	11	0.45	0.6605	Tukey-Kramer	1.0000	0.05	-10.8780	16.4907	-22.3095	27.9222
sal*conc	**20**	**1.5**	**20**	**2.5**	-0.4070	6.3208	11	-0.06	0.9498	Tukey-Kramer	1.0000	0.05	-14.3190	13.5049	-25.9407	25.1266
sal*conc	**20**	**2**	**20**	**2.5**	-3.2134	6.2174	11	-0.52	0.6155	Tukey-Kramer	1.0000	0.05	-16.8977	10.4709	-28.3293	21.9025

Data from Sea Oats - Stefanie Gilliam
Proc Univariate

The UNIVARIATE Procedure
Variable: Resid (Residual)

Moments			
N	81	**Sum Weights**	81
Mean	0	**Sum Observations**	0
Std Deviation	7.25556666	**Variance**	52.6432475
Skewness	-0.0842354	**Kurtosis**	2.94147959
Uncorrected SS	4211.4598	**Corrected SS**	4211.4598
Coeff Variation	.	**Std Error Mean**	0.80617407

Basic Statistical Measures			
Location		**Variability**	
Mean	0.00000	**Std Deviation**	7.25557
Median	-0.27577	**Variance**	52.64325
Mode	.	**Range**	49.47893
		Interquartile Range	5.39565

Tests for Location: Mu0=0				
Test	**Statistic**		**p Value**	
Student's t	**t**	0	**Pr > |t|**	1.0000

Sign	**M**	-1.5	**Pr >= |M|**	0.8243
Signed Rank	**S**	-30.5	**Pr >= |S|**	0.8869

Tests for Normality

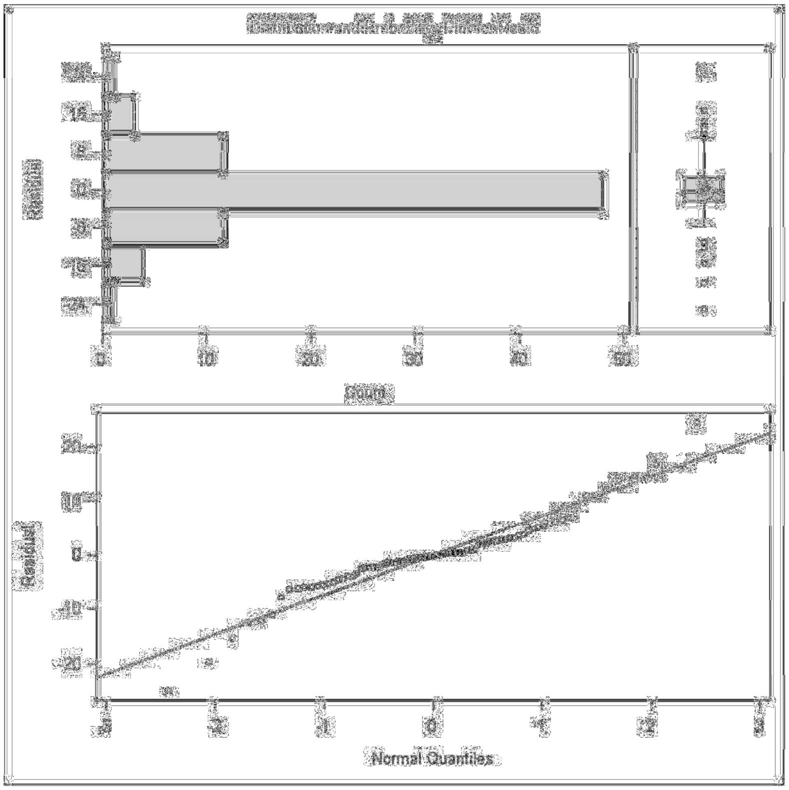
Test	Statistic		p Value	
Shapiro-Wilk	**W**	0.936496	**Pr < W**	0.0006
Kolmogorov-Smirnov	**D**	0.121079	**Pr > D**	<0.0100
Cramer-von Mises	**W-Sq**	0.347176	**Pr > W-Sq**	<0.0050
Anderson-Darling	**A-Sq**	1.891485	**Pr > A-Sq**	<0.0050

Quantiles (Definition 5)

Quantile	Estimate
100% Max	24.439637
99%	24.439637
95%	11.853604
90%	6.915851
75% Q3	2.949258
50% Median	-0.275771
25% Q1	-2.446396
10%	-6.182849
5%	-12.249413
1%	-25.039288
0% Min	-25.039288

Extreme Observations

Lowest		Highest	
Value	**Obs**	**Value**	**Obs**
-25.0393	63	11.8536	5
-19.5323	64	13.5677	43
-15.2841	56	14.5053	72
-12.3869	54	16.6143	31
-12.2494	45	24.4396	61



Data from Sea Oats - Stefanie Gilliam
LSMeans

Obs	Effect	sal	conc	Estimate	StdErr	DF	tValue	Probt	Alpha	Lower	Upper
1	sal	0	_	-1.2601	2.2165	11	-0.57	0.5811	0.05	-6.1386	3.6185
2	sal	2	_	5.3111	2.3381	11	2.27	0.0442	0.05	0.1649	10.4573
3	sal	20	_	6.0706	2.2374	11	2.71	0.0202	0.05	1.1460	10.9951
4	conc	_	1	5.9144	2.6438	11	2.24	0.0469	0.05	0.09540	11.7335
5	conc	_	1.5	4.2050	2.6643	11	1.58	0.1428	0.05	-1.6591	10.0690
6	conc	_	2	0.04101	2.5240	11	0.02	0.9873	0.05	-5.5143	5.5963
7	conc	_	2.5	3.3351	2.6257	11	1.27	0.2302	0.05	-2.4440	9.1141
8	sal*conc	0	1	2.2266	4.4695	11	0.50	0.6282	0.05	-7.6106	12.0638
9	sal*conc	0	1.5	-0.03341	4.4695	11	-0.01	0.9942	0.05	-9.8706	9.8038
10	sal*conc	0	2	-3.5375	4.3220	11	-0.82	0.4305	0.05	-13.0501	5.9751
11	sal*conc	0	2.5	-3.6960	4.4695	11	-0.83	0.4258	0.05	-13.5332	6.1413
12	sal*conc	2	1	13.1167	4.6332	11	2.83	0.0163	0.05	2.9192	23.3142
13	sal*conc	2	1.5	4.5544	4.8921	11	0.93	0.3718	0.05	-6.2130	15.3219
14	sal*conc	2	2	-1.6270	4.4695	11	-0.36	0.7227	0.05	-11.4642	8.2102
15	sal*conc	2	2.5	5.2003	4.7005	11	1.11	0.2922	0.05	-5.1455	15.5461
16	sal*conc	20	1	2.4000	4.6332	11	0.52	0.6147	0.05	-7.7975	12.5975

17	sal*conc	20	1.5	8.0938	4.4695	11	1.81	0.0975	0.05	-1.7434	17.9311
18	sal*conc	20	2	5.2875	4.3220	11	1.22	0.2467	0.05	-4.2251	14.8001
19	sal*conc	20	2.5	8.5009	4.4695	11	1.90	0.0837	0.05	-1.3363	18.3381

Data from Sea Oats - Stefanie Gilliam
Proc RSreg

The RSREG Procedure

Coding Coefficients for the Independent Variables		
Factor	**Subtracted off**	**Divided by**
sal	10.000000	10.000000
conc	1.750000	0.750000

Response Surface for Variable value	
Response Mean	3.179136
Root MSE	8.836638
R-Square	0.2138
Coefficient of Variation	277.9572

Regression	DF	Type I Sum of Squares	R-Square	F Value	Pr > F
Linear	2	659.042359	0.0885	4.22	0.0183
Quadratic	2	568.200698	0.0763	3.64	0.0310
Crossproduct	1	365.391697	0.0491	4.68	0.0337
Total Model	5	1592.634754	0.2138	4.08	0.0025

Residual	DF	Sum of Squares	Mean Square
Total Error	75	5856.463285	78.086177

Parameter	DF	Estimate	Standard Error	t Value	Pr > |t|	Parameter Estimate from Coded Data
Intercept	1	22.598167	11.613498	1.95	0.0554	16.085896
sal	1	2.652105	1.390808	1.91	0.0604	3.768126
conc	1	-23.424811	13.908852	-1.68	0.0963	-0.994415
sal*sal	1	-0.151136	0.064935	-2.33	0.0226	-15.113595
conc*sal	1	0.427101	0.197441	2.16	0.0337	3.203256
conc*conc	1	5.093690	3.933384	1.29	0.1993	2.865201

Factor	DF	Sum of Squares	Mean Square	F Value	Pr > F
sal	3	1316.711433	438.903811	5.62	0.0016
conc	3	660.527574	220.175858	2.82	0.0446

Data from Sea Oats - Stefanie Gilliam
Proc RSreg

The RSREG Procedure
Canonical Analysis of Response Surface Based on Coded Data

Factor	Critical Value	
	Coded	Uncoded
sal	0.135050	11.350498
conc	0.098041	1.823531

Predicted value at stationary point: 16.291591

Eigenvalues	Eigenvectors	
	sal	conc
3.006766	0.088045	0.996116
-15.255161	0.996116	-0.088045

Stationary point is a saddle point.

Data from Sea Oats - Stefanie Gilliam
Proc RSreg

The REG Procedure
Model: MODEL1
Dependent Variable: value

Number of Observations Read	81
Number of Observations Used	81

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	659.04236	329.52118	3.79	0.0270
Error	78	6790.05568	87.05200		
Corrected Total	80	7449.09804			

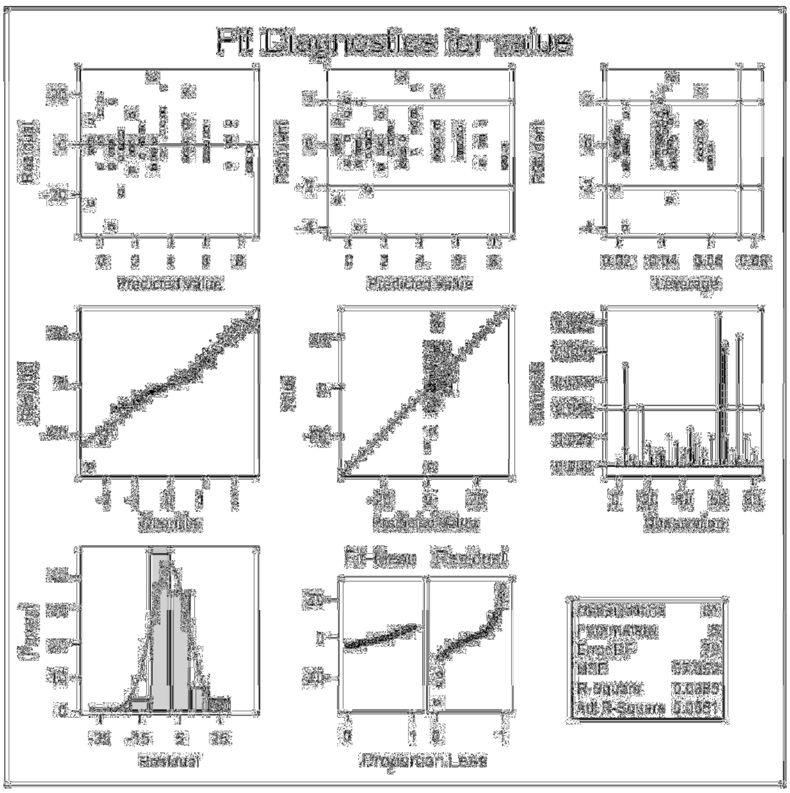
Root MSE	9.33017	R-Square	0.0885
Dependent Mean	3.17914	Adj R-Sq	0.0651
Coeff Var	293.48120		

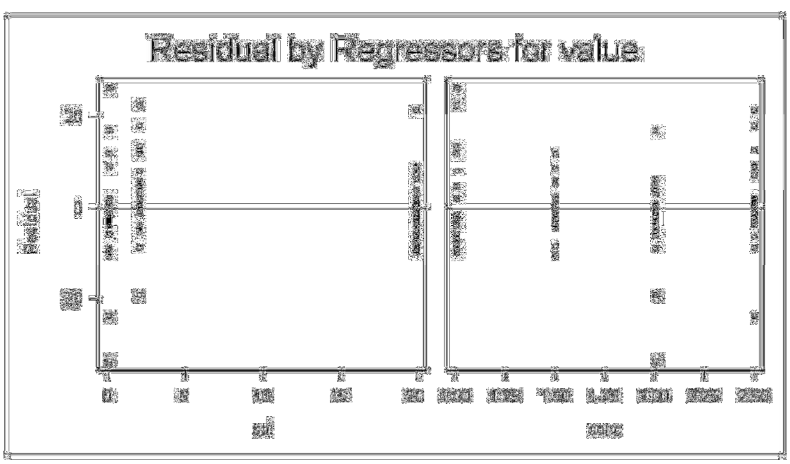
Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	**1**	5.43287	3.58302	1.52	0.1335
sal	**1**	0.27854	0.11373	2.45	0.0166
conc	**1**	-2.45228	1.88438	-1.30	0.1970

Data from Sea Oats - Stefanie Gilliam
Proc RSreg

The REG Procedure
Model: MODEL1
Dependent Variable: value





Data from Sea Oats - Stefanie Gilliam
Proc GLMSelect

The GLMSELECT Procedure

Data Set	WORK.ONE
Dependent Variable	value
Selection Method	Backward
Select Criterion	Significance Level
Stop Criterion	Significance Level
Stay Significance Level (SLS)	0.05
Effect Hierarchy Enforced	None

Number of Observations Read	81
Number of Observations Used	81

Dimensions	
Number of Effects	12
Number of Parameters	12

Data from Sea Oats - Stefanie Gilliam
Proc GLMSelect

The GLMSELECT Procedure

Backward Selection Summary				
Step	**Effect Removed**	**Number Effects In**	**F Value**	**Pr > F**
0		12		
1	**sal*sal*conc**	11	0.00	0.9909
2	**conc**	10	0.03	0.8610
3	**conc*conc*conc**	9	0.47	0.4951
4	**sal*conc**	8	1.30	0.2576
5	**conc*conc**	7	1.96	0.1660

Selection stopped because the next candidate for removal has SLS < 0.05.

Stop Details					
Candidate For	**Effect**	**Candidate Significance**		**Compare Significance**	
Removal	sal*conc*conc*conc	0.0181	<	0.0500	(SLS)

Data from Sea Oats - Stefanie Gilliam
Proc GLMSelect

The GLMSELECT Procedure
Selected Model

The selected model is the model at the last step (Step 5).

Effects:	Intercept sal sal*sal sal*conc*conc sal*conc*conc*conc sal*sal*conc*conc sal*sal*con*con*conc

Analysis of Variance				
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**
Model	6	1700.10360	283.35060	3.65
Error	74	5748.99444	77.68911	
Corrected Total	80	7449.09804		

Root MSE	8.81414
Dependent Mean	3.17914
R-Square	0.2282
Adj R-Sq	0.1657
AIC	442.24882
AICC	444.24882
SBC	376.00996

Parameter Estimates				
Parameter	**DF**	**Estimate**	**Standard Error**	**t Value**
Intercept	1	-1.296207	1.636745	-0.79
sal	1	15.882259	4.482288	3.54
sal*sal	1	-0.786642	0.224350	-3.51
sal*conc*conc	1	-11.600753	4.460060	-2.60
sal*conc*conc*conc	1	3.824946	1.582040	2.42
sal*sal*conc*conc	1	0.586712	0.223996	2.62
sal*sal*con*con*conc	1	-0.192848	0.079449	-2.43

Data from Sea Oats - Stefanie Gilliam
Proc GLM

The GLM Procedure

Number of Observations Read	81
Number of Observations Used	81

Data from Sea Oats - Stefanie Gilliam
Proc GLM

The GLM Procedure

Dependent Variable: value

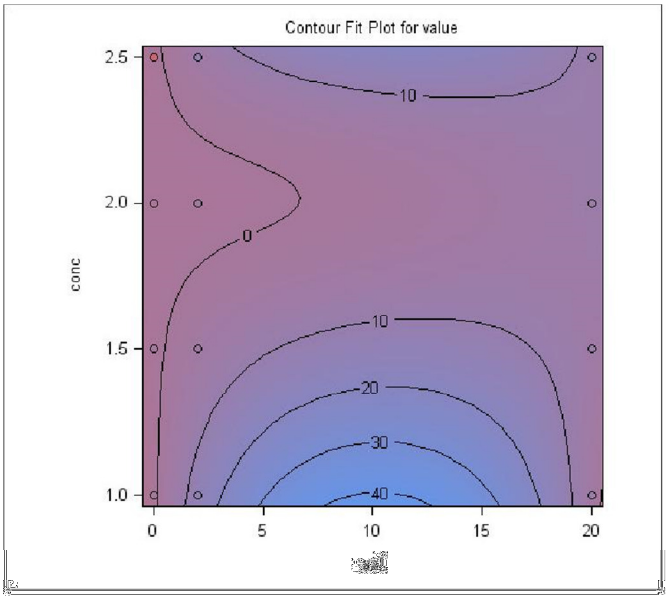
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1700.103595	283.350599	3.65	0.0032
Error	74	5748.994444	77.689114		
Corrected Total	80	7449.098040			

R-Square	Coeff Var	Root MSE	value Mean
0.228229	277.2496	8.814143	3.179136

Source	DF	Type I SS	Mean Square	F Value	Pr > F
sal	1	511.6138462	511.6138462	6.59	0.0123
sal*sal	1	420.4933343	420.4933343	5.41	0.0227
sal*conc*conc	1	53.0584170	53.0584170	0.68	0.4112
sal*conc*conc*conc	1	0.0000658	0.0000658	0.00	0.9993
sal*sal*conc*conc	1	257.1974221	257.1974221	3.31	0.0729
sal*sal*con*con*conc	1	457.7405100	457.7405100	5.89	0.0176

Source	DF	Type III SS	Mean Square	F Value	Pr > F
sal	1	975.4054217	975.4054217	12.56	0.0007
sal*sal	1	955.1301206	955.1301206	12.29	0.0008
sal*conc*conc	1	525.5948595	525.5948595	6.77	0.0112
sal*conc*conc*conc	1	454.1255805	454.1255805	5.85	0.0181
sal*sal*conc*conc	1	533.0038258	533.0038258	6.86	0.0107
sal*sal*con*con*conc	1	457.7405100	457.7405100	5.89	0.0176

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-1.29620690	1.63674524	-0.79	0.4309
sal	15.88225904	4.48228820	3.54	0.0007
sal*sal	-0.78664232	0.22435002	-3.51	0.0008
sal*conc*conc	-11.60075309	4.46006013	-2.60	0.0112
sal*conc*conc*conc	3.82494631	1.58203994	2.42	0.0181
sal*sal*conc*conc	0.58671237	0.22399595	2.62	0.0107
sal*sal*con*con*conc	-0.19284819	0.07944855	-2.43	0.0176



Data from Sea Oats - Stefanie Gilliam
Proc GLM

The GLM Procedure

Number of Observations Read	81
Number of Observations Used	81

Data from Sea Oats - Stefanie Gilliam
Proc GLM

The GLM Procedure

Dependent Variable: value

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	1988.334359	180.757669	2.28	0.0191
Error	69	5460.763681	79.141503		
Corrected Total	80	7449.098040			

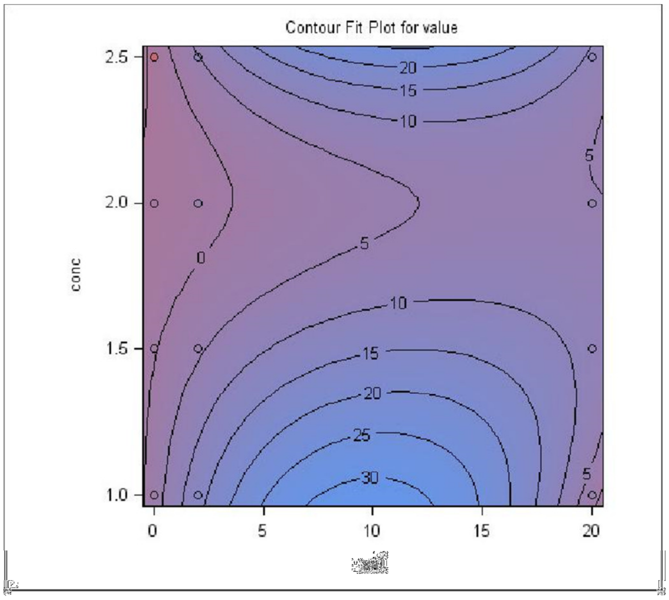
R-Square	Coeff Var	Root MSE	value Mean
0.266923	279.8292	8.896151	3.179136

Source	DF	Type I SS	Mean Square	F Value	Pr > F
sal	1	511.6138462	511.6138462	6.46	0.0133
sal*sal	1	420.4933343	420.4933343	5.31	0.0242
conc	1	151.0722506	151.0722506	1.91	0.1715
conc*conc	1	144.0636265	144.0636265	1.82	0.1817
conc*conc*conc	1	86.1178575	86.1178575	1.09	0.3005
sal*conc	1	371.5035756	371.5035756	4.69	0.0337
sal*conc*conc	1	100.5549429	100.5549429	1.27	0.2636
sal*conc*conc*conc	1	23.3775952	23.3775952	0.30	0.5885

sal*sal*conc	1	36.7132216	36.7132216	0.46	0.4981
sal*sal*conc*conc	1	139.6597549	139.6597549	1.76	0.1884
sal*sal*con*con*conc	1	3.1643533	3.1643533	0.04	0.8421

Source	DF	Type III SS	Mean Square	F Value	Pr > F
sal	1	0.50223707	0.50223707	0.01	0.9367
sal*sal	1	1.72036978	1.72036978	0.02	0.8832
conc	1	1.33397094	1.33397094	0.02	0.8971
conc*conc	1	2.84858686	2.84858686	0.04	0.8501
conc*conc*conc	1	3.84438150	3.84438150	0.05	0.8262
sal*conc	1	0.38655132	0.38655132	0.00	0.9445
sal*conc*conc	1	2.14991936	2.14991936	0.03	0.8696
sal*conc*conc*conc	1	4.69459424	4.69459424	0.06	0.8083
sal*sal*conc	1	0.01035364	0.01035364	0.00	0.9909
sal*sal*conc*conc	1	1.05518344	1.05518344	0.01	0.9084
sal*sal*con*con*conc	1	3.16435326	3.16435326	0.04	0.8421

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-4.46250001	89.7759105	-0.05	0.9605
sal	5.98782408	75.1651965	0.08	0.9367
sal*sal	-0.53423942	3.6234909	-0.15	0.8832
conc	22.28250001	171.6298714	0.13	0.8971
conc*conc	-19.49571429	102.7605841	-0.19	0.8501
conc*conc*conc	4.29285714	19.4775955	0.22	0.8262
sal*conc	10.03671383	143.6117944	0.07	0.9445
sal*conc*conc	-14.14189417	85.8022435	-0.16	0.8696
sal*conc*conc*conc	3.95163139	16.2248071	0.24	0.8083
sal*sal*conc	-0.07918033	6.9226593	-0.01	0.9909
sal*sal*conc*conc	0.47749471	4.1352972	0.12	0.9084
sal*sal*con*con*conc	-0.15633157	0.7818192	-0.20	0.8421



Data from Sea Oats - Stefanie Gilliam
Proc GLM

The GLM Procedure

Number of Observations Read	96
Number of Observations Used	96

Data from Sea Oats - Stefanie Gilliam
Proc GLM

The GLM Procedure

Dependent Variable: death

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	1.03125000	0.09375000	0.68	0.7560
Error	84	11.62500000	0.13839286		
Corrected Total	95	12.65625000			

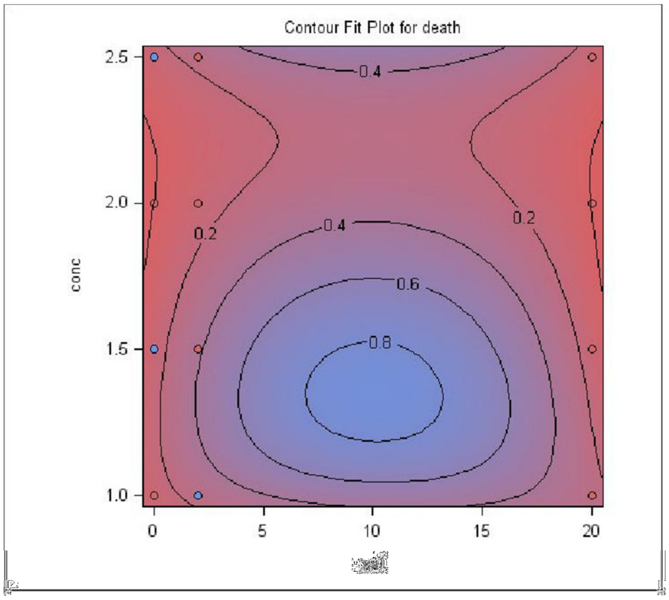
R-Square	Coeff Var	Root MSE	death Mean
0.081481	238.0876	0.372012	0.156250

Source	DF	Type I SS	Mean Square	F Value	Pr > F
sal	1	0.02524038	0.02524038	0.18	0.6704
sal*sal	1	0.41225962	0.41225962	2.98	0.0880
conc	1	0.10208333	0.10208333	0.74	0.3929
conc*conc	1	0.09375000	0.09375000	0.68	0.4128
conc*conc*conc	1	0.25208333	0.25208333	1.82	0.1808
sal*conc	1	0.02748397	0.02748397	0.20	0.6570

sal*conc*conc	1	0.04172390	0.04172390	0.30	0.5844
sal*conc*conc*conc	1	0.02116529	0.02116529	0.15	0.6967
sal*sal*conc	1	0.00168269	0.00168269	0.01	0.9125
sal*sal*conc*conc	1	0.02077610	0.02077610	0.15	0.6994
sal*sal*con*con*conc	1	0.03300137	0.03300137	0.24	0.6266

Source	DF	Type III SS	Mean Square	F Value	Pr > F
sal	1	0.03107774	0.03107774	0.22	0.6368
sal*sal	1	0.03707494	0.03707494	0.27	0.6061
conc	1	0.04407358	0.04407358	0.32	0.5740
conc*conc	1	0.05081301	0.05081301	0.37	0.5462
conc*conc*conc	1	0.05625000	0.05625000	0.41	0.5255
sal*conc	1	0.03371994	0.03371994	0.24	0.6229
sal*conc*conc	1	0.03127548	0.03127548	0.23	0.6357
sal*conc*conc*conc	1	0.02859591	0.02859591	0.21	0.6506
sal*sal*conc	1	0.03944959	0.03944959	0.29	0.5948
sal*sal*conc*conc	1	0.03628384	0.03628384	0.26	0.6100
sal*sal*con*con*conc	1	0.03300137	0.03300137	0.24	0.6266

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-1.749999999	3.58031261	-0.49	0.6263
sal	-1.326388890	2.79900047	-0.47	0.6368
sal*sal	0.069444445	0.13416961	0.52	0.6061
conc	3.874999998	6.86656228	0.56	0.5740
conc*conc	-2.499999999	4.12581161	-0.61	0.5462
conc*conc*conc	0.500000000	0.78426996	0.64	0.5255
sal*conc	2.649768521	5.36810976	0.49	0.6229
sal*conc*conc	-1.533333335	3.22545819	-0.48	0.6357
sal*conc*conc*conc	0.278703704	0.61312299	0.45	0.6506
sal*sal*conc	-0.137384259	0.25731942	-0.53	0.5948
sal*sal*conc*conc	0.079166667	0.15461178	0.51	0.6100
sal*sal*con*con*conc	-0.014351852	0.02938994	-0.49	0.6266



Data from Sea Oats - Stefanie Gilliam
Proc GLMSelect

The GLMSELECT Procedure

Data Set	WORK.TWO
Dependent Variable	death
Selection Method	Backward
Select Criterion	Significance Level
Stop Criterion	Significance Level
Stay Significance Level (SLS)	0.05
Effect Hierarchy Enforced	None

Number of Observations Read	96
Number of Observations Used	96

Dimensions	
Number of Effects	12
Number of Parameters	12

Data from Sea Oats - Stefanie Gilliam
Proc GLMSelect

The GLMSELECT Procedure

Backward Selection Summary				
Step	**Effect Removed**	**Number Effects In**	**F Value**	**Pr > F**
0		12		

1	**sal*conc*conc*conc**	11	0.21	0.6506
2	**sal**	10	0.02	0.8884
3	**sal*sal*con*con*conc**	9	0.19	0.6651
4	**sal*sal**	8	0.40	0.5281
5	**sal*sal*conc*conc**	7	0.53	0.4685
6	**sal*conc*conc**	6	0.02	0.8987
7	**conc**	5	1.53	0.2192
8	**conc*conc*conc**	4	1.39	0.2411
9	**conc*conc**	3	1.17	0.2812
10	**sal*conc**	2	1.58	0.2122
11	**sal*sal*conc**	1	0.73	0.3944

Backward selection stopped because all remaining effects are required.

Data from Sea Oats - Stefanie Gilliam
Proc GLMSelect

The GLMSELECT Procedure
Selected Model

The selected model is the model at the last step (Step 11).

Effects:	Intercept

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value
Model	0	1.57366E-10	.	.
Error	95	12.65625	0.13322	
Corrected Total	95	12.65625		

Root MSE	0.36500
Dependent Mean	0.15625
R-Square	0.0000
Adj R-Sq	0.0000
AIC	-94.51491
AICC	-94.38588
SBC	-189.95057

Parameter Estimates

Parameter	DF	Estimate	Standard Error	t Value

Intercept	1	0.156250	0.037252	4.19

Data from Sea Oats - Stefanie Gilliam
Proc RSreg

The RSREG Procedure

Coding Coefficients for the Independent Variables		
Factor	**Subtracted off**	**Divided by**
sal	10.000000	10.000000
conc	1.750000	0.750000

Response Surface for Variable death	
Response Mean	0.156250
Root MSE	0.365079
R-Square	0.0522
Coefficient of Variation	233.6505

Regression	DF	Type I Sum of Squares	R-Square	F Value	Pr > F
Linear	2	0.127324	0.0101	0.48	0.6218
Quadratic	2	0.506010	0.0400	1.90	0.1558
Crossproduct	1	0.027484	0.0022	0.21	0.6508
Total Model	5	0.660817	0.0522	0.99	0.4275

Residual	DF	Sum of Squares	Mean Square
Total Error	90	11.995433	0.133283

Parameter	DF	Estimate	Standard Error	t Value	Pr > |t|	Parameter Estimate from Coded Data
Intercept	1	0.496394	0.441371	1.12	0.2637	0.495660
sal	1	0.092521	0.052094	1.78	0.0791	0.015625
conc	1	-0.471154	0.528692	-0.89	0.3752	-0.050481
sal*sal	1	-0.004253	0.002418	-1.76	0.0820	-0.425347
conc*sal	1	-0.003365	0.007411	-0.45	0.6508	-0.025240
conc*conc	1	0.125000	0.149043	0.84	0.4039	0.070313

Factor	DF	Sum of Squares	Mean Square	F Value	Pr > F
sal	3	0.464984	0.154995	1.16	0.3284
conc	3	0.223317	0.074439	0.56	0.6438

Data from Sea Oats - Stefanie Gilliam
Proc RSreg

The RSREG Procedure
Canonical Analysis of Response Surface Based on Coded Data

	Critical Value	
Factor	**Coded**	**Uncoded**
sal	0.007676	10.076756
conc	0.360352	2.020264

Predicted value at stationary point: 0.486624

	Eigenvectors	
Eigenvalues	**sal**	**Conc**
0.070634	-0.025437	0.999676
-0.425668	0.999676	0.025437

Stationary point is a saddle point.

APPENDIX C. ADDITIONAL PLANT WEIGHT DATA

otal Plant Weight																									
Veight July 12, 2013																									
A		B		C		D		E		F		G		H		I		J		K		L			
1	8.1	1	13.3	1	11.3	1	11.9	1	19.1	1	7.2	1	22.4	1	7.7	1	14.8	1	9.5	1	29.5	1	8.2		
2	12.2	2	26.1	2	15.1	2	12.2	2	26.8	2	10.1	2	24.2	2	15.6	2	7.4	2	9.9	2	21.2	2	5.1		
3	20.9	3	25.4	3	8.2	3	33.2	3	10.5	3	16.1	3	4.4	3	30.7	3	5.8	3	9.1	3	8	3	9.4		
4	4.4	4	10.9	4	11.9	4	11.1	4	14	4	27	4	12.4	4	8.1	4	20.4	4	13.5	4	18.4	4	12.1		
eight August 9, 2013																									
A		B		C		D		E		F		G		H		I		J		K		L			
1	5.3	1	11.4	1	11.5	1	12.4	1	45.2	1	3.7	1	18.2	1	14.9	1	15.6	1	7.8	1	29.6	1	12.03		
2	11.3	2	17.4	2	14.6	2	9.4	2	35.3	2	7.8	2	24.1	2	33.7	2	7.2	2	19.6	2	25.2	2	6.3		
3	14.2	3	16.8	3	9.5	3	29.4	3	22.3	3	23.9	3	10.3	3	9.2	3	7.8	3	8.1	3	9.2	3	9.7		
4	9.2	4	10.5	4	29.5	4	10.9	4	8.2	4	35.5	4	12.9	4	10.1	4	19.8	4	20.7	4	21.5	4	10.8		
nge in Weight																									
A		B		C		D		E		F		G		H		I		J		K		L			
1	-2.8	1	-1.9	1	0.2	1	0.5	1	26.1	1	-3.5	1	-4.2	1	7.2	1	0.8	1	-1.7	1	0.1	1	3.8		
2	-0.9	2	-8.7	2	-0.5	2	-2.8	2	8.5	2	-2.3	2	-0.1	2	18.1	2	-0.2	2	9.7	2	4.0	2	1.2		
3	-6.7	3	-8.6	3	1.3	3	-3.8	3	11.8	3	7.8	3	5.9	3	-21.5	3	2.0	3	-1.0	3	1.2	3	0.3		
4	4.8	4	-0.4	4	17.6	4	-0.2	4	-5.8	4	8.5	4	0.5	4	2.0	4	-0.6	4	7.2	4	3.1	4	-1.3		
Ending Weight																									
A		B		C		D		E		F		G		H		I		J		K		L			
1	2.6	1	5.3	1	5.2	1	5.7	1	22.4	1	1.9	1	8.2	1	6.8	1	6.2	1	3.2	1	16.2	1	5.9		
2	4.9	2	8.4	2	6.8	2	4.1	2	15.7	2	3.2	2	11.5	2	14.2	2	2.5	2	7.3	2	8.4	2	3.4		
3	5.6	3	7.2	3	3.8	3	13.5	3	10.3	3	10.5	3	5.4	3	4.7	3	2.8	3	4.2	3	3.6	3	5.1		
4	3.9	4	4.3	4	11.4	4	5.1	4	3.9	4	17.1	4	6.3	4	4.2	4	7.1	4	11.1	4	6.8	4	4.6		
oot from Total Weight																									
A		B		C		D		E		F		G		H		I		J		K		L			
1	48.69	1	46.37	1	45.22	1	45.97	1	49.56	1	51.35	1	45.05	1	45.64	1	39.74	1	41.03	1	54.73	1	49.04		
2	43.48	2	48.25	2	46.58	2	43.62	2	44.48	2	41.03	2	47.72	2	42.14	2	34.72	2	37.24	2	33.33	2	53.97		
3	39.41	3	42.76	3	40.00	3	45.92	3	46.19	3	43.93	3	52.43	3	51.09	3	35.90	3	51.85	3	39.13	3	52.58		
4	42.44	4	40.91	4	38.64	4	46.79	4	47.56	4	48.17	4	48.84	4	41.58	4	35.86	4	53.62	4	31.63	4	42.59		
Average	43.50		44.57		42.61		45.57		46.95		46.12		48.51		45.11		36.56		45.94		39.71		49.55	Total Average	44.56
Standard Dev	3.86		3.34		3.88		1.36		2.15		4.56		3.06		4.37		2.19		8.04		10.52		5.08	Total Standard Dev	2.59

otal Plant Weight																									
ight August 30, 2013																									
A		B		C		D		E		F		G		H		I		J		K		L			
1	18.4	1	7.9	1	17	1	10.6	1	7.2	1	19.2	1	17.2	1	12.6	1	7.1	1	8.4	1	5.2	1	13.9		
2	6.8	2	3.2	2	14.4	2	10.3	2	9.4	2	13.1	2	21.4	2	16.5	2	22.3	2	9.6	2	9.9	2	6.6		
3	2.9	3	16.4	3	37.2	3	32.3	3	10.1	3	13.1	3	9.6	3	17.4	3	13.3	3	16	3	12.3	3	26.5		
4	10.8	4	18.7	4	12.2	4	10.5	4	17.1	4	18.3	4	6	4	23.1	4	8.4	4	8.1	4	6.5	4	12.3		
ht September 30, 2013																									
A		B		C		D		E		F		G		H		I		J		K		L			
1	12.3	1	10.6	1	13.8	1	19.3	1	24.4	1	7.6	1	5.9	1	3.7	1	5.9	1	9.8	1	10.7	1	8.9		
2	11.7	2	16.8	2	6	2	7.6	2	9	2	17.4	2	3.3	2	18.3	2	19.4	2	4.6	2	13.4	2	6.9		
3	32.3	3	16.7	3	4.1	3	7.9	3	25.6	3	11.1	3	11.3	3	19.3	3	19.7	3	19.3	3	14.6	3	6.8		
4	11.3	4	5.1	4	10	4	12.3	4	9.7	4	21.1	4	10.1	4	35.7	4	15.4	4	8.2	4	25.8	4	7.6		
nge in Weight																									
A		B		C		D		E		F		G		H		I		J		K		L			
1	-6.1	1	2.7	1	-3.2	1	8.7	1	17.2	1	-11.6	1	-11.3	1	-8.9	1	-1.2	1	8.4	1	5.2	1	13.9		
2	4.9	2	13.6	2	-8.4	2	-2.7	2	-0.4	2	4.3	2	-18.1	2	1.8	2	-2.9	2	9.6	2	9.9	2	6.6		
3	29.4	3	0.3	3	-33.1	3	-24.4	3	15.5	3	-2	3	1.7	3	1.9	3	6.4	3	16	3	12.3	3	26.5		
4	0.5	4	-13.6	4	-2.2	4	1.8	4	-7.4	4	2.8	4	4.1	4	12.6	4	7	4	8.1	4	6.5	4	12.3		
Ending Weight																									
A		B		C		D		E		F		G		H		I		J		K		L			
1	4.7	1	4.3	1	6.4	1	7.6	1	2.3	1	5.6	1	2.5	1	1.4	1	2.3	1	4.7	1	6.5	1	3.8		
2	4.5	2	7.7	2	3.5	2	3.1	2	4.5	2	7.7	2	1.5	2	3.3	2	9.21	2	1.9	2	3.8	2	2.7		
3	10.5	3	2.5	3	2.9	3	3.3	3	11.3	3	7.3	3	5.6	3	5.6	3	9.2	3	8.9	3	5.6	3	4.7		
4	5.3	4	2.1	4	4.5	4	4.4	4	5.6	4	6.3	4	3.3	4	2.4	4	6.6	4	3.3	4	9.8	4	3		
oot from Total Weight																									
A		B		C		D		E		F		G		H		I		J		K		L			
1	38.21	1	40.57	1	46.38	1	39.38	1	9.43	1	73.68	1	42.37	1	37.84	1	38.98	1	47.96	1	60.75	1	42.70		
2	38.46	2	45.83	2	58.33	2	40.79	2	50.00	2	44.25	2	45.45	2	18.03	2	47.47	2	41.30	2	28.36	2	39.13		
3	32.51	3	14.97	3	70.73	3	41.77	3	44.14	3	65.77	3	49.56	3	29.02	3	46.70	3	46.11	3	38.36	3	69.12		
4	46.90	4	41.18	4	45.00	4	35.77	4	57.73	4	29.86	4	32.67	4	6.72	4	42.86	4	40.24	4	37.98	4	39.47		
Average	39.02		35.64		55.11		39.43		40.32		53.39		42.51		22.90		44.00		43.91		41.36		47.60	Total Average	42.10
Standard Dev	5.93		13.98		12.01		2.63		21.34		20.02		7.19		13.49		3.91		3.72		13.73		14.43	Total Standard Dev	6.30

APPENDIX D. ULTRASOL DATA SHEET

Ultrasol™

3-15-28

Water Soluble Fertilizer
Ultrasol™ Hydroponic Plus

PRODUCT DESCRIPTION:
When used with calcium nitrate this formulation provides essential nutrients for hydroponic applications, including grow bags using pine bark or perlite media, rockwool and NFT. Ideal for growing tomatoes, strawberries, cucumbers, herbs and floral crops.

GUARANTEED ANALYSIS:
Total Nitrogen (N)..3%
  3.0% Nitrate Nitrogen
Available Phosphate (P_2O_5).................... 15%
Soluble Potash (K_2O) 28%
Magnesium (Mg) 5.3%
  5.3% Water Soluble Magnesium (Mg)
Sulfur (S) Combined 9.0%
Boron (B) 0.05%
Copper (Cu) 0.07%
  0.07% Chelated Copper (Cu)
Iron (Fe) 0.30%
  0.30% Chelated Iron (Fe)
Manganese (Mn) 0.10%
  0.10% Chelated Manganese (Mn)
Molybdenum (Mo) 0.01%
Zinc (Zn) 0.04%
  0.04% Chelated Zinc (Zn)

DERIVED FROM:
Potassium Nitrate, Potassium Sulfate, Mono Potassium Phosphate, Magnesium Sulfate, Iron EDTA, Manganese EDTA, Copper EDTA, Zinc EDTA, Boric Acid, Sodium Molybdate. F1367

POTENTIAL BASICITY: 125 lbs calcium carbonate equivalent per ton.

SOLUBILITY (max.): 2.0 lbs per gallon.

Instructions:
Total nitrogen and calcium levels are controlled by using varying amounts of calcium nitrate simultaneously with this product. All micronutrients and other essential nutrients are contained in this formula.

Suggested use rates:
Use enough of Ultrasol™ 3-15-28 Hydroponic to supply 30 ppm N and no more. This supplies proper levels of all nutrients except nitrogen and calcium which should be added separately to avoid formation of precipitate.

13 oz. per 100 gallons = 30 ppm N

E.C. at 30 ppm N = 1.1 mS

Use the following amounts of calcium nitrate per 100 gallons as required for specific crop and growing environment:

Ounces	ppm N	ppm Ca	mS/cm
4.5	50	61	0.37
9	100	123	0.74
13.5	150	184	1.11
18	200	245	1.48

NC.231528

Net Weight 25 lbs

Suggested total nitrogen for bag culture tomatoes is 100-130 ppm N. Other hydroponic systems use higher nitrogen levels. Consult crop and system guidelines.

Example for bag culture tomato:

Ultrasol™ 3-15-28	30 ppm N	1.10 mS
Calcium Nitrate	100 ppm N	0.74 mS
Combined	130 ppm N	1.84 mS

Use half of rates above during initial growth until seedlings are well established. Levels shown above are sufficient for all stages of mature growth and fruit production. Monitor crop tissue levels regularly to manage nutrient levels.

The above shown solution provides the following nutrient levels in ppm:

Total Nitrogen	130
Ammoniacal N	7
Nitrate N	123
Phosphorus	66
Potassium (K)	240
Calcium	123
Magnesium	52
Sulfur	90
Boron	0.5
Copper	0.7
Iron	3
Molybdenum	0.1
Manganese	1
Zinc	0.4

SQM
THE WORLDWIDE BUSINESS FORMULA

MANUFACTURED BY:
SQM North America
2727 Paces Ferry Rd, Bldg 2, Ste 1425
Atlanta, GA 30339
Information: 1-800-667-8528

VITA

Stefanie Gilliam was born in Dhahran, Saudi Arabia to Charles and Barbara Gilliam. She graduated *cum laude* from Runnels High School, Baton Rouge, Louisiana, in May 2005, then attended the University of Georgia, Athens, Georgia on an Academic Common Market Scholarship. She transferred to Louisiana State University in January 2007 with a TOPS scholarship and completed her bachelor's degree in Biological Engineering in May 2011. She entered the Graduate School in the Department of Engineering at Louisiana State University in August 2011. She was awarded a Charles E. Severance Endowed Fellowship and a graduate assistantship while completing her degree. She is a candidate for a Master's of Science degree in December 2013.